ELECTRIC POWER RESEARCH INSTITUTE

2015 TECHNICAL REPORT

Corrosion Assessment of Balance-of-Plant Structures and Equipment

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All or a portion of the requirements of the EPRI Nuclear Quality Assurance Program apply to this product.

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Product Description

This report provides an assessment of the corrosion of systems, structures, and components (SSC) of nuclear power plants (NPPs) in the United States and Canada, including aboveground and belowground tanks, concrete structures and piping, heat exchangers, and large metallic components.

Background

The balance of plant (BOP) of an NPP contains a wide variety of SSC constructed of materials susceptible to degradation mechanisms in certain environments. The potential for degradation in the BOP can be reduced through cathodic protection (CP) and other ways, such as coatings. If properly timed, corrosion mitigation strategies can prevent costly repairs and eliminate unplanned outages. The responses to a 2013 survey conducted by the Electric Power Research Institute (EPRI) related to SSC, corrosion, and cathodic protection indicated the importance of early identification of corrosion. Subsequently, EPRI identified a need to perform additional research and investigation of corrosion experiences of balance-of-plant SSC—concrete structures and piping, heat exchangers, tanks, and large metallic components.

Objectives

The objective of the research presented in this report was to identify the SSC most susceptible to corrosion, the methods with which the corrosion is identified and mitigated, and the potential research and development (R&D) needs in the area of SSC corrosion. The report includes the following information:

- An overview of the organization of the personnel responsible for corrosion measures for SSC at NPPs
- Condition assessment techniques used by NPP personnel for the identification of corrosion
- Operating experience and mitigation strategies related to corrosion of SSC at NPPs
- Findings, recommendations, and potential research and development related to corrosion at NPPs

Approach

The project involved a series of surveys and interviews with NPP staff. This information was compiled into a single document that served as input about corrosion conditions found at NPPs.

Results

The results indicated the current causes of and mitigation techniques for corrosion in balance-of-plant SSC and the application, use, and repair of corrosion-inhibiting systems—coatings and CP. Examples of additional R&D opportunities are as follows:

- The applicability of corrosion-inhibitor injections for tanks
- Better inspection techniques for unexposed tank bottoms
- Monitoring of CP effectiveness for concrete structures
- Improved seals for concrete repair
- Shorter coating repairs

Applications, Value, and Use

This report can be used by NPP personnel responsible for corrosion-related activities for buried piping, coatings, structures, CP, heat exchangers, and so on. The report imparts a better understanding of the organizational responsibilities for the management of degradation, condition assessment techniques, operating experience, and mitigation strategies. Report users will also gain the ability to identify, prioritize, and mitigate corrosion in BOP SSC, which might result in fewer needed repairs and replacements.

Keywords

Balance of plant (BOP)
Corrosion assessment
Corrosion inspection techniques
Corrosion mitigation strategies
Degradation mechanisms
Galvanic corrosion

Abstract

The balance of plant (BOP) contains a wide variety of structures, systems, and components constructed of materials susceptible to degradation due to corrosion in certain environments. The threat of degradation in the BOP can be mitigated through the application of cathodic protection and other mitigation measures, such as coatings, water treatment, and corrosion-resistant materials. If properly timed, the installation or upgrading of corrosion mitigation strategies can prevent the need to perform costly repairs and reduce the threat of unplanned outages required to implement repairs.

The objective of this project was to perform a corrosion assessment of nuclear power plants in order to develop an understanding of organizational responsibilities for the management of degradation, condition assessment techniques, operating experience, and mitigation strategies implemented. The project involved a series of surveys and interviews with plant staff. The results were analyzed to identify areas where additional research would benefit nuclear power plant operations.

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Section 1: Introduction

Nuclear power plants contain a diverse combination of structures, systems, and components (SSCs) with specific design functions. Every SSC has one or more specified functions, the contribution of these individual functions is necessary to support safe and reliable plant operation. Some SSC functions are relied upon during and following design-basis events and others are more directly associated with power generation.

Traditionally plant management strategies have been developed for the identification and correction of degradation of SSCs which are relied upon during and following design-basis events (i.e., safety related). However, a number of SSCs which are required for reliable plant operation do not meet safety related criteria. In particular, the balance of plant (BOP) is composed primarily of SSCs considered to be non-safety related.

Although these SSCs are non-safety related, they are necessary to support normal plant operation. These non-safety related SSCs are generally constructed with similar materials and operated in similar service conditions as safety-related components. Therefore, similar degradation mechanisms can affect the ability of non-safety related SSCs to perform specific functions. As a result, it is important to manage degradation of these non-safety related SSCs to maintain reliable plant operation.

1.1 Project Basis

In 2013, EPRI conducted a survey on the topics of corrosion and cathodic protection (CP) related issues for BOP SSCs. Eleven responses from the US and Canada were received. The following was ascertained by EPRI based on the limited survey response:

- There are some corrosion issues in the BOP, particularly for coastal plants.
- The condition of many SSCs was reported as being "unknown" due to BOP SSCs being lower priority items (i.e., non-safety related, Tier-3 items, which do not require performance monitoring versus safety related Tier-1 items which do require performance monitoring).
- Most of the SSCs, where applicable, are not protected from corrosion through the application of cathodic protection (CP) or other means.

Based on survey results and the importance of early identification of corrosion, EPRI identified a need to perform additional investigation in the area of BOP corrosion. Results and further discussion on findings of the 2013 EPRI survey are contained in Appendix A.

1.2 Report Purpose and Objectives

The threat of degradation can be mitigated through the use of corrosion resistant materials, application of CP, and other mitigation measures, such as coatings and water treatment. If properly timed, the implementation of corrosion mitigation strategies can prevent the need to perform costly repairs and reduce the threat of unplanned outages needed to implement repairs.

The objective of this project was to perform a corrosion assessment of nuclear power plants in order to develop an understanding of the current corrosion state. Items specifically addressed during this project included:

- Identification of important BOP structures and equipment
- Relevant plant operating experience
- Plant responsibilities
- Applicable corrosion control programs and commitments
- Condition assessment technologies being used
- Results from inspections
- Corrosion mitigation practices being employed

The outcome of this project was to assist in understanding industry best practices for the management of BOP corrosion. In addition, special attention was paid to the identification of gaps where additional research and development may improve overall reliability of BOP SSCs.

1.3 Report Organization

The body of this report documents the approach and the outcome of key tasks associated with this project. The appendices of this report contain additional details on analysis conducted and supporting documentation.

1.4 Acronyms

Several acronyms are used repeatedly in the text herein; explanation is provided below for these common acronyms.

AERM – Aging Effect Requiring Management

ANI – American Nuclear Insurers

AST – Aboveground Storage Tank

BOP – Balance of Plant

BWR – Boiling Water Reactor

CIPP – Cured In Place Piping

CP – Cathodic Protection

GL – Generic Letter

ILI – In-Line Inspection

ISG – Interim Staff Guidance

MIC – Microbiologically Influenced Corrosion

NEIL – Nuclear Electric Insurance Limited

NFPA – National Fire Protection Association

NPP – Nuclear Power Plant

NRC – Nuclear Regulatory Commission

NSSS – Nuclear Steam Supply Systems

OE – Operating Experience

PCCP – Pre-Stressed Concrete Cylinder Pipe

PHWR – Pressurized Heavy Water Reactor

PM – Preventative Maintenance

PWR – Pressurized Water Reactor

SCC – Stress Corrosion Cracking

SMP - Structural Monitoring Program

SSC – Structures, Systems, and Components

UT – Ultrasonic Testing

Section 2: Industry Survey

Participation in the 2013 industry survey conducted by EPRI was eleven responses which yielded broad information on the current BOP corrosion state of the North American nuclear fleet. As a result, a secondary industry survey was determined necessary to assess the current BOP corrosion state across the North American nuclear fleet as part of this project.

Development of a second survey, referred to herein as the 2014 industry survey, began with a detailed review of the 2013 EPRI survey results to identify trends. Following the review, the 2014 industry survey was developed and sent to member plants with 23 questions covering the following categories:

- General Corrosion
- Buried and Aboveground Storage
- Concrete Structures and Piping
- Heat Exchangers
- Large Metallic Plant Components or Structures

In total, 42 responses representing 34 sites were received from participants located throughout the United States and Canada. Figure 2-1 provides a geographic representation of the survey responses.

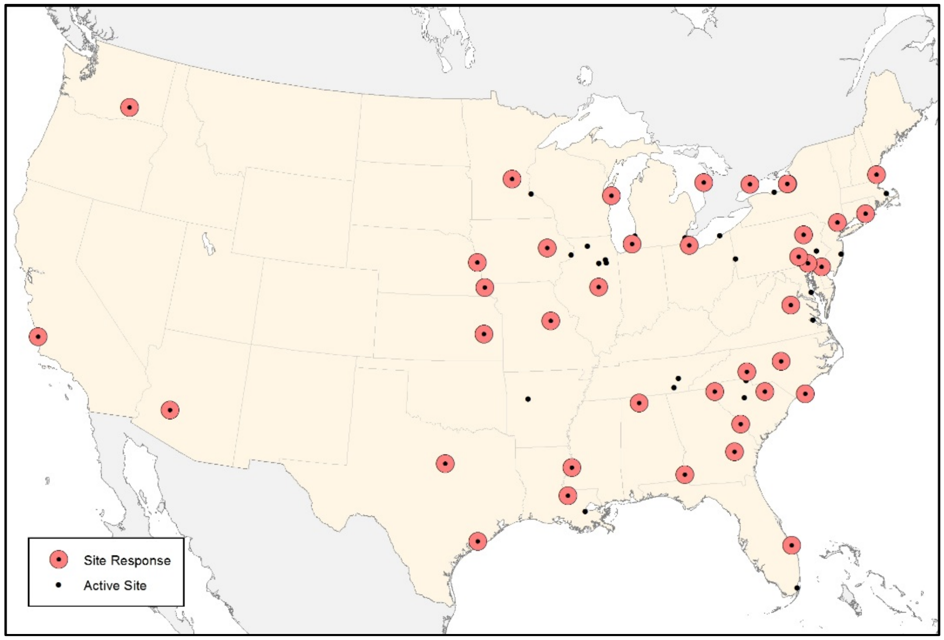

Figure 2-1
Geographic Location of Plant Responses for Survey (RED)

All survey responses were then combined and characterized based on a variety of attributes such as reactor type and location, as discussed in Appendix B. Figure 2-2 is an example of one such characterization conducted to identify trends in material categories which have experienced degradation. During this characterization carbon steel/low alloy steel was observed as the material most commonly identified with a degradation history by participants, which received 62% of the total responses. The second most commonly identified material with a history of degradation was ductile/cast iron, which received 23% of the total responses. The remaining material categories received less than 5% of the total responses, respectively.

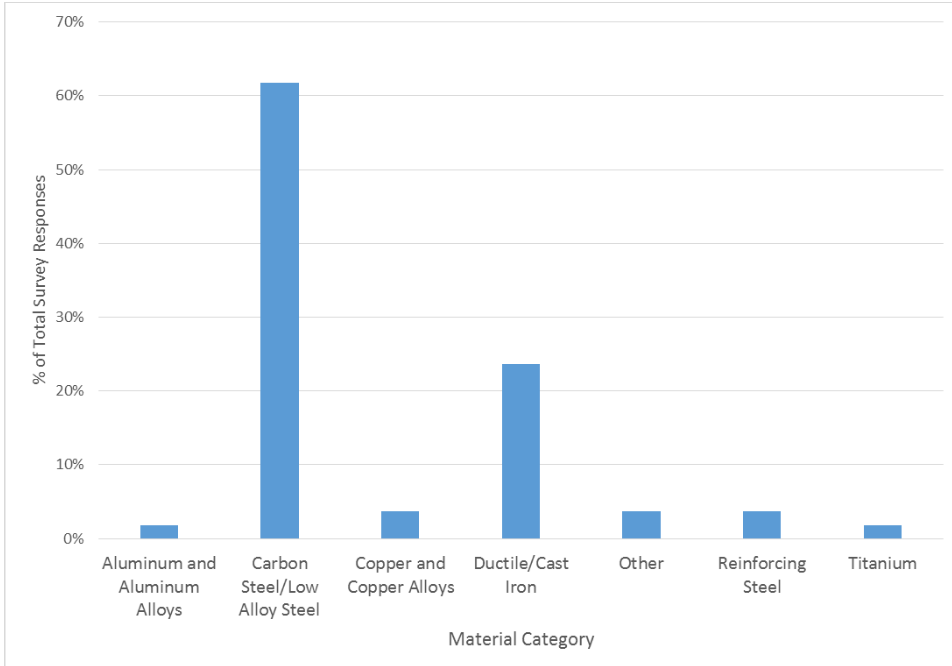

Figure 2-2
Degraded Materials by Material Category

Similarly, multi-attribute characterizations were performed to understand the impact of environment on material corrosion. For example, survey results received from plants located within 30 miles of the coastline were sub-categorized as coastal and then compared, as shown in Figure 2-3. The coastal categorization was developed to account for potential variation in environmental conditions affecting the corrosion performance specific materials. It should be noted, the 30-mile criteria used for coastal/inland categorization was based upon corrosion engineering experience and validated through a sensitivity study.

The multi-attribute characterization of materials and coastal proximity indicates carbon steel/low alloy steel was observed as the material most frequently identified with a history of degradation for both coastal and inland plants, receiving 62% and 58% of the total category responses, respectively. This is considered an indication that coastal proximity has minimal impact on the material category most frequently reported with a history of degradation.

When performing multi-attribute comparisons, it was also observed that not all materials have a degradation history at both coastal and inland locations. Material categories which were identified by either coastal or inland locations accounted for less than 10% of the total category responses. As such, the variance in the identified material categories with a history of degradation is not considered significant.

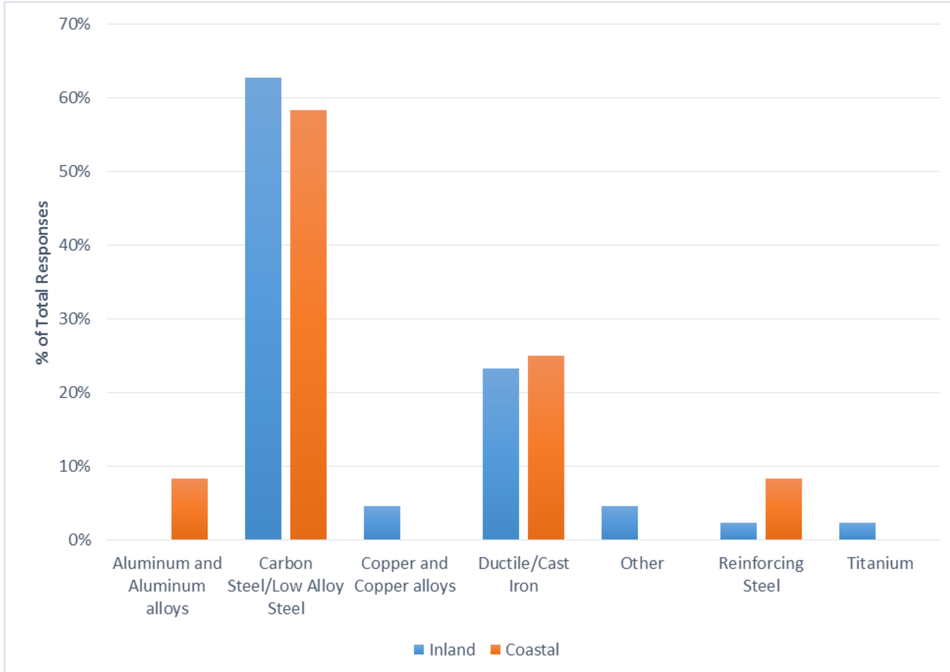

Figure 2-3
Degraded Materials by Material Category and Coastal Location

In addition to specific questions related to corrosion, participants were also asked if they would be willing to provide input on plant operating experience (OE). Twenty three participants agreed to provide support and were subsequently interviewed to evaluate plant responsibilities, program commitments, and to ascertain specific OE regarding BOP SSCs at their respective site. Figure 2-4 provides an overview of sites which participated in follow-on interviews.

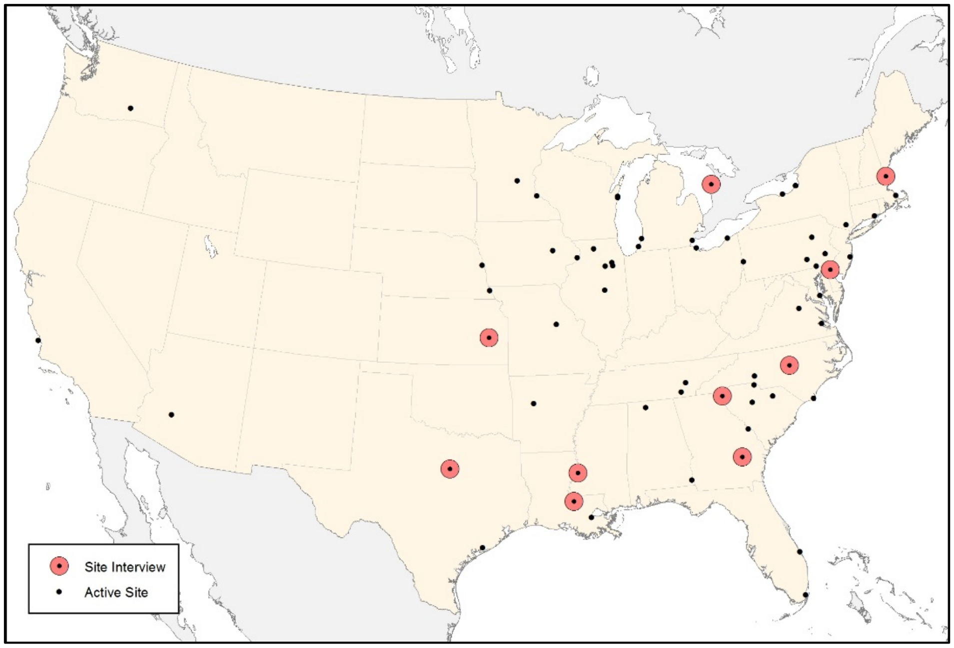

Figure 2-4
Geographic Location of Plant Interview Participants

Knowledge gained through interviews of survey participants are incorporated in applicable sections throughout this document.

Section 3: Organizational Responsibilities

Aging management programs are generally employed at nuclear power plants to ensure SSCs degradation does not adversely impact operations. These aging management programs generally require cross-department support to effectively address SSC degradation. The relationship between plant organizations for aging management is well defined and, to some degree, consistent across the North American fleet for specific components. This defined structure is a result of their overall importance to safe plant operation and license renewal efforts.

Unfortunately, aging management programs related to BOP components are often not as well defined compared to safety-related SSCs. This resulted in a wide range of responses regarding responsibilities for addressing BOP corrosion during the interview process. The following list provides a summary of the responsibilities for BOP corrosion identification and mitigation during the interview process:

- Plant staff is expected to be vigilant for adverse conditions, such as the presence of corrosion. Therefore, the identification of corrosion in the BOP is the responsibility of the entire plant staff, rather than being assigned to a particular department or program.
- Monitoring of specialized components, such as heat exchangers, is conducted by engineering program owner(s).
- The preventative maintenance (PM) program includes routine tasks to perform monitoring of specific components. The frequency and method for inspection of in-scope SSCs are reviewed periodically to ensure that inspection methods and mitigation strategies are appropriate for applicable degradation mechanisms.
- Non-license operators, also referred to as building operators, are trained on corrosion mechanisms. Non-license operators routinely observe plant components which greatly reduces the period of time between corrosion initiation and detection. These individuals are then responsible for reporting adverse conditions to be resolved by the appropriate plant staff.
- A small full time crew is responsible for identification and mitigation of atmospheric corrosion through the application of coatings to exposed metal areas.

Upon identification of corrosion in the BOP, the majority of plants indicated that degraded conditions were resolved. They entered in the corrective actions program and resolved through work management processes. During the interview process, these work management systems were identified as vulnerable in the mitigation of BOP corrosion issues.

Work management processes are designed to prioritize the execution of plant maintenance to ensure safe and reliable plant operations. This includes balancing preventive and remedial measures that are necessary to ensure SSCs are capable of performing as intended. This is commonly accomplished through the implementation of a systematic maintenance program which includes the following [1]:

- A systematic evaluation of the functions and objectives of SSCs to determine the necessary maintenance activities and the related requirements
- A focus on long-term maintenance objectives that establishes a proactive, as opposed to reactive, maintenance program
- A reliability centered approach to maintenance
- Maintenance planning and scheduling that is derived from overall program objectives

Use of such systematic approaches results in preferential allocation of plant resources to SSCs classified as safety related or generation critical. As such, BOP corrosion issues are often considered lower priority, which results in timeliness issues with the implementation of mitigation actions. Delays in the implementation can result in the need to perform more aggressive mitigation, such as material replacement instead of coatings.

Issues with ownership for the identification and mitigation corrosion in a timely manner were identified as cultural issues. These issues have resulted in a culture where “run to failure” is considered an acceptable approach to BOP corrosion management at some sites. Such cultures may result in adverse effects on the long term reliability of the BOP SSCs.

Section 4: Conditions Assessment Techniques

Periodic condition assessments are often used to ensure safe and reliable plant operation. Condition assessments may be conducted based on requirements set forth by outside organizations including, but not limited to, the Institute of Nuclear Power Operators (INPO), Nuclear Regulatory Commission (NRC), National Fire Protection Association (NFPA), Nuclear Energy Institute (NEI), Nuclear Electric Insurance Limited (NEIL), and World Association of Nuclear Operators (WANO). Other condition assessments are conducted on a voluntary basis by utilities to maintain high levels of equipment reliability.

Selection of the appropriate condition assessment technique is of utmost importance regardless of the component type or assessment purpose. The 2014 industry survey included questions to gain further understanding of the inspection techniques being used by utilities to assess the condition of various equipment categories. In addition, survey participants were also asked to provide input on which assessment techniques were considered to be effective.

Initially, survey results were analyzed without consideration for equipment category to assist in the identification of overall industry trends. This analysis resulted in identification of two trends:

- Utilities appear to prefer visual inspection and ultrasonic testing (UT) technologies for inspection of plant components. This trend is based on 51% of survey responses, relative to implemented inspection techniques, selecting visual/UT technologies.
- A large portion of inspection techniques implemented are not viewed as effective. This trend is based on 42 inspection techniques receiving at least one response for implementation and only 27 for effectiveness. This represents a 36% reduction between implemented and effective inspection techniques.

Table 4-1 provides a summary of the most frequently selected inspection techniques for implementation and effectiveness survey questions for each equipment category.

Table 4-1
Most Frequently Implemented and Effective Inspection Techniques

Equipment Category	Inspection Techniques Implemented	Top Three Effective Inspection Techniques
Buried and Aboveground Tanks	Visual Inspection Manual UT Liquid Penetrant	Visual Inspection Manual UT Automated UT
Concrete Structures and Piping	Visual Inspection Measurement of Cracks Coring, Petrography, and Sounding	Visual Inspection Measurement of Cracks Core Extraction and Testing
Heat Exchangers	Eddy Current Visual/Enhanced Visual UT/Shell or Tube Thickness Monitoring, Water Sampling	Conventional UT Eddy Current, Visual/Enhanced Visual Remote Visual Inspection, Shell or Tube Thickness Monitoring
Large Metallic Plant Components or Structures	Visual Inspection Conventional UT Magnetic Particle/Dye Penetrant	Visual Inspection Conventional UT Magnetic Particle/Dye Penetrant

A review of Table 4-1 indicates the inspection techniques most frequently selected as implemented and effective on an equipment category basis do not always align. For example, sounding was selected four times as an implemented inspection technique, but only once as an effective inspection technique. In such cases, limited detection ability is presumed to be the influencing factor in the overall reduction in survey responses relative to effectiveness. In other cases, it may be considered infeasible to implement the inspection techniques viewed as effective due to the destructive nature, cost, limited resources, or spatial constraints of the technique(s). As a result, it may be necessary to use less effective techniques as a screening tool to determine if more effective techniques are necessary.

A detailed analysis of survey results related to inspection techniques for each equipment category is provided in Appendix B.

Section 5: Operating Experience

Operating Experience (OE) provides the opportunity to learn from events which have occurred throughout the industry. In particular, it is an opportunity to gain awareness of mistakes or events that have occurred at nuclear power plants (NPPs) and which have resulted in an undesirable outcome. Studying such OE is especially valuable when identifying areas where additional research may benefit BOP reliability.

The survey and interviews conducted as part of this project are valuable sources of OE related to BOP corrosion. One of the most significant pieces of OE is related to the components which are most often found degraded due to corrosion. Figure 5-1 provides a summary of component categories receiving at least ten (10) percent of survey responses indicating degradation has been found.

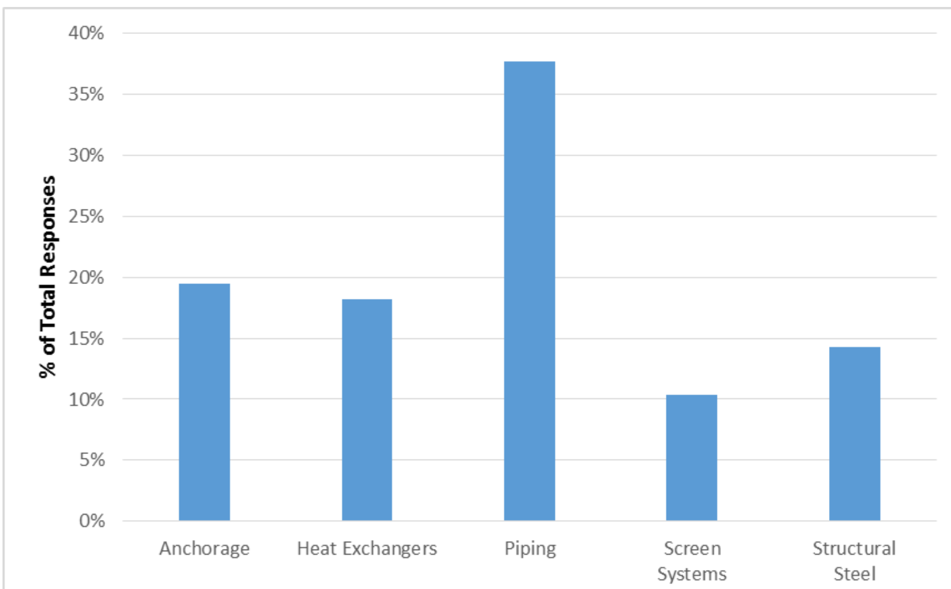

Figure 5-1
Degraded Component Categories, % of Total Responses

Piping was the most common equipment category with known degradation due to corrosion based on the entire survey response population, which may include multiple responses from individual participants. This is further supported by the fact that piping was identified by 76% of survey responses and during multiple plant interviews as a component with known degradation.

Piping is one of the most prevalent components in a nuclear power plant. Piping in safety related and high energy systems are routinely inspected in order to manage the effects of wall loss as part of various plant programs. It was ascertained from plant interviews that many of the low-pressure and non-safety related piping systems, which make up the majority of the BOP, are managed as a "run-to-failure" (or "run-to-maintenance") component. While this approach may be appropriate for some systems, such as floor drains inside of a building, other systems may have a substantial impact on plant reliability in the event of a failure.

The second most common equipment category found to be degraded due to corrosion is equipment anchorage. This equipment category is to some degree unique from other categories identified in Figure 5-1. Most of the equipment categories included in this survey are monitored as a part of engineering programs and can adversely affect system performance in the event of a failure.

Equipment anchorage, and to some extent structural steel, is often overlooked by plant staff due to the passive nature of its design function. While anchorage performs a passive function, it is essential for piping and equipment, such as pumps, to function properly and to prevent premature failure. Anchorage is commonly located in areas which are not easily observed as staff travel through the plant. Therefore, identification of anchorage degradation is everyone's responsibility. Some utilities have incorporated anchorage inspections into routine plant maintenance procedures to address this potential vulnerability.

While it is important to understand the type of equipment most commonly found degraded, it is also important to understand the type of degradation commonly experienced. Figure 5-2 provides the overall distribution of reported degradation mechanisms.

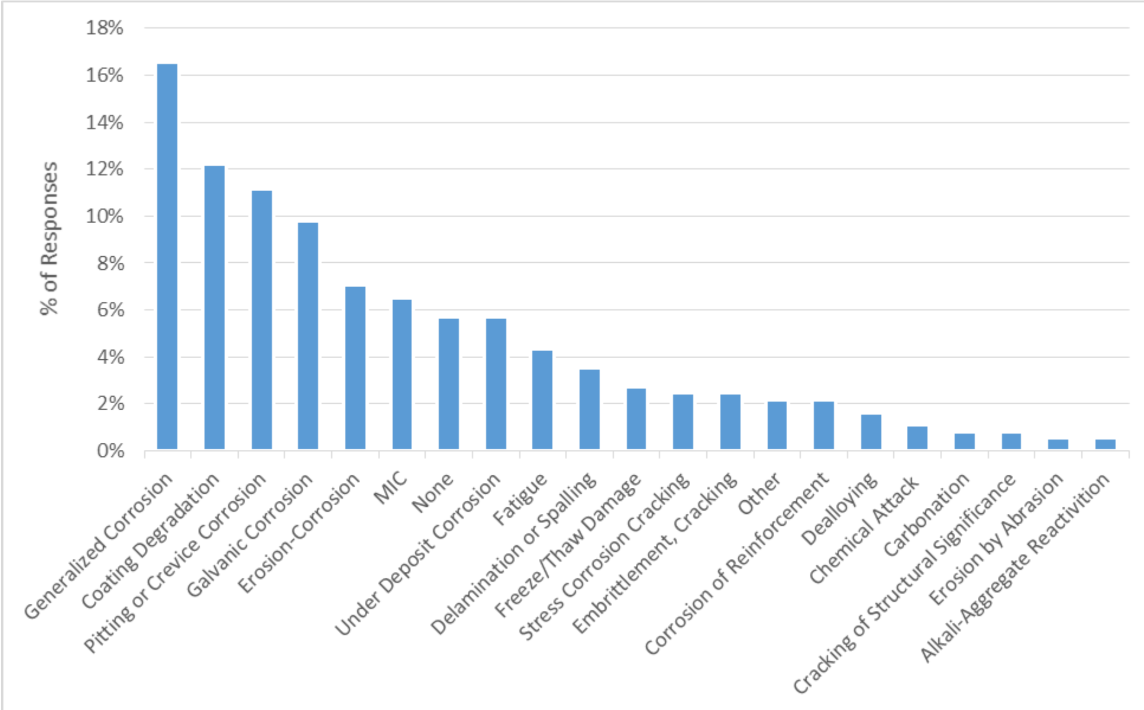

Figure 5-2
Degradation Mechanisms, % of Total Responses

Table 5-1 contains the three most commonly identified degradation mechanisms for each equipment category.

Table 5-1
Degradation Mechanisms

Equipment Category	Top Three Degradation Mechanisms Reported
Buried and Aboveground Tanks	1. Generalized Corrosion 2. Coating Degradation 3. Pitting or Crevice Corrosion
Concrete Structures and Piping	1. Delamination or Spalling 2. Freeze/Thaw Damage 3. Corrosion of Reinforcement
Heat Exchangers	1. Generalized Corrosion 2. Pitting or Crevice Corrosion 3. Coating Degradation
Large Metallic Plant Components or Structures	1. Generalized Corrosion 2. Galvanic Corrosion 3. Coating Degradation

No specific trends were identified from Figure 5-2 and Table 5-1. However, such information can be used as a tool for benchmarking plant inspection procedures for the ability to detect known degradation mechanisms. Additional OE related to BOP corrosion was provided during a number of plant interviews. Operating experience gained from plant interviews is incorporated within the Findings and Recommendations (Section 7) of this project.

Section 6: Mitigation Strategies

A number of mitigation strategies are available to extend the life of SSCs when corrosion is detected early. In addition to early detection, it is also important to select appropriate mitigation strategies based on service conditions and known degradation mechanisms. During the 2014 industry survey, respondents were asked which of the following mitigation strategies are most commonly implemented.

- Cathodic Protection – The reduction of corrosion rate by making the potentially degradable surface the cathode of an electrochemical cell.
- Coating/Lining – Application of a material to the interior (lining) or exterior (coating) of an SSC that will act as a physical barrier to isolate susceptible materials from a corrosive environment.
- Corrosion Resistant Material Replacement – Replacement of plant components, which based on their chemical composition, are resistant to the corrosive attributes for a given environment (e.g., stainless steel containing 6% molybdenum in a raw water system).
- Repair of Existing Components – Implementation of corrective actions to address observed degradation (e.g., weld overlay).
- Replacement in Kind – Replacement of degraded components with a new component constructed of the same material.
- Water Treatment – Use of chemicals and other treatment methods to reduce the corrosiveness of a process fluid (e.g., addition of biocides).

The results of the site-wide survey question are provided in Figure 6-1.

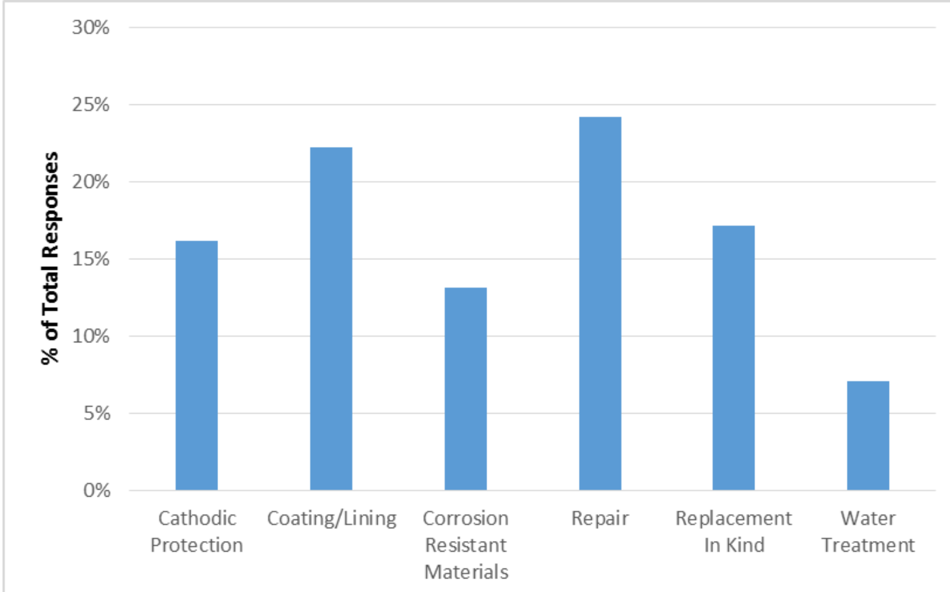

Figure 6-1
Most Utilized Mitigation Strategies, % of Total Responses

Three of the top four most commonly identified corrosion mitigation strategies are related to extending the life of existing SSCs rather than complete replacements. This trend was also observed in survey responses for individual equipment categories. Table 6-1 contains the most frequently selected mitigation techniques for implementation and effectiveness survey questions for each equipment category.

Table 6-1
Implemented and Effective Mitigation Stratagies

Equipment Category	**Implemented Inspection Strategies**	**Top Three Effective Mitigation Strategies**
Buried and Aboveground Tanks	1. Coating Repair 2. New Coatings/Lining 3. Cathodic Protection	1. Coating Repair 2. Original Cathodic Protection 3. Material Replacement, New Coating/Lining
Concrete Structures and Piping	1. Routing and Sealing 2. Grouting, Coating 3. Epoxy Injection	1. Coating 2. Routing and Sealing 3. Grouting
Heat Exchangers	1. Material Replacement 2. Coating Repair 3. Chemical Treatment	1. Material Replacement 2. Chemical Treatment 3. New Coatings/Linings, Offline Mechanical Cleaning
Large Metallic Plant Components or Structures	1. Coating Repair 2. Replacement In Kind 3. Structural Repair	1. Coating Repair 2. Replacement In Kind 3. Structural Repair

From Table 6-1, it can be observed that the most commonly identified corrosion mitigation strategies on an equipment level are also related to extending the life of existing SSCs rather than complete replacements. Survey responses of only one equipment category – heat exchangers – indicates material replacement was the most frequently selected mitigation strategy. This trend observed through multiple means in survey responses supports the need to perform research on methods for early identification of degradation and effective mitigation techniques to avoid the need to replace BOP SSCs.

Section 7: Findings and Recommendations

During the course of this project a number of findings and recommendations were developed based on survey results and plant interviews. This led to an increased understanding of the current corrosion state and the need for additional research. The following general findings and recommendations were determined to span several equipment categories. A summary of category specific findings and recommendations are contained in the following subsections, with further details contained in Appendix B.

- The majority of BOP components do not directly impact the ability of safety related components to perform a design basis function. As a result, a culture has developed at many sites to consider "run to failure" an acceptable approach to SSC management. During multiple interviews it was indicated that a culture with a "run-to-failure" approach has resulted in plant reliability issues. This has prompted the need for focused effort by plant management to change the culture to increase reliable plant operation by preventing BOP failures due to corrosion.

  Additionally, it was noted that a decline in BOP reliability can create unnecessary operator burdens. Such burdens may impact the ability to implement corrective measures in a timely manner in the event of a plant transient. As such, declining BOP reliability may be perceived as a challenge to nuclear safety by oversight organizations and regulatory bodies.

- Multiple interviewees indicated the primary causes of coating degradation, and the subsequent corrosion related issues, are "self-induced." The primary causes of self-induced coating damage included errors in the application process and mechanical damage from excavations and scaffolding installations. Additional guidance on the application and maintenance of coatings to avoid self-induced degradation is an area where BOP reliability may be increased by ensuring the intended level of corrosion control is properly provided and maintained.

- The application of coatings/linings is a common approach for mitigating the threat of corrosion regardless of the specific component. Several interview participants indicated training courses available on the topic of coatings are primarily focused on the application of new coatings. While this is an important topic, it does not address issues associated with the management of aging coatings used at NPPs. The preparation of a course on the management of aging coatings may benefit BOP reliability by providing utility members the information necessary to make life cycle management decisions appropriate for NPP specific coating conditions.

- The number of plant SSCs which utilize CP to mitigate the threat of corrosion varies greatly across the industry. While the specific components protected varies, survey results and interviews indicate there is an adverse trend in the industry regarding CP system performance benchmarking before and after plant modifications to ensure system effectiveness is not adversely effected. Communicating the importance of such benchmarking is an area where BOP reliability may benefit by ensuring degraded corrosion controls are identified and remediated promptly. Early identification and remediation of degraded corrosion controls is essential to preventing unnecessary damage to SSCs located in a corrosive environment.
- Both survey responses and interviews indicate many plant processes associated with the BOP are focused on the identification of degraded piping components. Although a piping specific category was not included the 2014 industry survey, it is important to consider the effects of this culture on survey results and overall plant management strategies.
- Several interview participants expressed interest in inspection techniques for the identification of degradation in specific components. Upon further review it was determined that 1) a technique had already been developed and tested by EPRI or 2) a technique was under development and testing by EPRI. Such responses validates EPRI research is meeting industry needs.

A number of equipment category specific findings and recommendations were also identified. The majority of these findings and recommendations from the EPRI survey and the 2014 industry survey are contained in Appendices A and B, respectively. The following sections contain a summary of significant findings for each equipment category.

7.1 Buried and Aboveground Storage Tanks

The following findings and recommendations are associated with buried and aboveground tanks:

- The most frequently used inspection techniques for tanks have limited detection capabilities. Detection capabilities for inspection methods most commonly selected in the survey generally correspond to the degradation mechanisms most commonly detected. Additional research on appropriate methods for tank inspection, informed inspection location selection, and online monitoring are areas where BOP reliability may be increased. This research would ensure selection of appropriate inspection techniques for plausible degradation mechanisms based on service conditions.
- Several utilities use CP for the protection of tank bottoms. Polarized potentials can vary significantly across a tank bottom depending on CP current distribution. Measurements of polarized potential measurements across tank bottoms is a challenge due to access limitations. The Oil and Gas industry uses soil access tubes below tank bottoms to measure potentials to

evaluate CP system effectiveness. Due to challenges associated with soil tube installation, additional research on methods for the evaluation of CP system effectiveness for tank bottoms may benefit BOP reliability by ensuring effective corrosion control is applied to the entire bottom.

- The Oil and Gas industry has used the injection of corrosion inhibitors beneath tank bottoms as an additional corrosion mitigation strategy. Additional research on the applicability of corrosion inhibitor injections for tank bottom corrosion mitigation may provide an alternative for sites where CP is ineffective or impractical for corrosion control.

7.2 Concrete Structures and Piping

The following findings and recommendations are associated with concrete structures and piping:

- A number of survey participants indicated CP is used as a corrosion mitigation strategy for concrete reinforcement. The majority of those respondents using CP also indicate the system is operating in an effective manner. However, during the course of this project, a few participants indicated the original CP system has not been refurbished or augmented. As a CP system ages the ability to provide effective protection decreases. Additional research into monitoring CP system effectiveness for concrete reinforcement is an area which may benefit BOP reliability due to the substantial cost and complexity associated with remediation of degraded concrete SSCs (e.g., buildings). At the time of this project, EPRI has conducted research on CP of reinforced concrete structures [2] to address this industry need.
- Joints in concrete are commonly sealed through grouting or installation of elastomers. An important function of sealing is to prevent the infiltration of moisture. Corrosion of concrete reinforcement can occur as a result of water intrusion through degraded seals. Such degradation can adversely impact strength of the effected structure. Therefore, concrete sealing degradation is an area were additional research may increase BOP reliability by ensuring SSC integrity is not adversely affected by water infiltration.
- Years of experience and mentoring generally form the basis for qualification of plant staff to perform structural monitoring. While these are two key components of an effective monitoring program, written guidance on the monitoring process and documentation are equally important. Guidance on monitoring and documentation of findings is an area where additional research may increase BOP reliability and provide consistency across the fleet for future industry benchmarking.

7.3 Heat Exchangers

Information obtained through surveys and interviews indicate robust inspection programs are in place for the identification of heat exchanger corrosion and subsequent mitigation. As a result, no areas of additional research related to corrosion of heat exchangers were identified.

7.4 Large Metallic Components or Structures

The following findings and recommendations are associated with large metallic components:

- Coating delamination commonly occurs as a result of damage during installation and/or repairs due to a combination of errors in the application process and damage from scaffolding. Such degrdation compromises the corrosion control measures for the structure and exposes susceptible materials to a corrosive environment. This can result in metal loss which adversely impacts the ability of the component to perform the intended function. As a result, long term maintenance of coatings is an area where additional research may benefit BOP reliability by preventing uncessary degrdation of SSCs following coating damage.
- Installation and repair of coatings requires signficant duration of time to complete. As a result, installation of coatings for large components, such as water boxes, is commonly performed in phases over the course of multiple refueling outages. Methods to reduce installation time is an area where additional research may benefit BOP reliability by encouraging early mitigation without impacting refueling outage duration.

7.5 Other Components

A number of findings and recommendations were developed during the review of survey results and plant interviews which do not fit into specific equipment categories of the 2014 industry survey but are related to piping systems. The number of observations and inquires received justifies documentation outside of the equipment categories. The following findings and recommendations are associated with piping systems:

- Microbiologically influenced corrosion (MIC) can significantly reduce the service life of piping components. Several interviewees expressed interest in additional research related to locating and identifying MIC. A variety of past EPRI works have focused on the topic of MIC. During the course of this project references [3, 4, 5, and 6] were identified to be valuable documentary sources for the utility member. Although research has been completed, the development of additional guidance on informed selection of inspection locations for the identification of MIC is an area where additional research may benefit BOP reliability by increasing the likelihood of detection. Early detection of MIC allows utilities to schedule the implementation of remediation actions rather than incurring additional costs associated with the correction of emergent issues (i.e., leaks).
- Fiberglass is a corrosion resistant material. However, several sites indicated degradation of fiberglass piping has adversely impacted plant operations. Additional research into the degradation of fiberglass piping is an area in which additional research may benefit BOP reliability by preventing unnecessary failures.

- Inspection and remediation of piping systems, in particular for buried piping, is an area where multiple interview participants expressed interest in additional research. Areas of specific interest include the development of in-line inspection tools (ILI) for nuclear plant piping configurations, additional research to gain regulatory acceptance of guided wave testing and the installation of cured in place piping (CIPP).

  In addition to the specific needs discussed above, the following EPRI documents related to inspection and remediation were identified as potential resources to address other inquiries during the course of this project for plant reviews:

  - *Nondestructive Evaluation: Buried Pipe NDE Reference Guide-Revision 2*, Product ID: 1025220 [7]
  - *Nondestructive Evaluation: Buried Pipe In-Line NDE Depth Sizing Procedure*, Product ID: 1025231 [8]
  - *EPRI's Intermediate Diameter Buried Piping Instrumented Vehicle – Evaluation*, Product ID: 1022926 [9]
  - *Buried Pipe Guided Wave Examination Reference Document*, Product ID: 1019115 [10]
  - *Nondestructive Evaluation: Buried Pipe Guided Wave Analysis Tools*, Product ID: 3002000466 [11]
  - *Obtaining Credit for Guided Wave as a Buried Pipe Direct Examinatio*n, Product ID: 3002000468 [12]

Section 8: References

1. Maintenance, Surveillances and In-service Inspection in Nuclear Power Plants, International Atomic Energy Agency, No. NS-G-2.6. 2002.
2. *Cathodic Protection of Reinforced Concrete Building Structures*. EPRI, Palo Alto, CA: Product ID: 3002003090.
3. *Detection and Control of Microbiologically Influenced Corrosion*. EPRI, Palo Alto, CA. 1990. NP-6815-D.
4. *Source Book for Microbiologically Influenced Corrosion in Nuclear Power Plants*. EPRI, Palo Alto, CA: 1998. NP-5580.
5. *A Study of Microbiologically Influenced Corrosion in Nuclear Power Plants and a Practical Guide for Countermeasures*. EPRI, Palo Alto, CA: 1986. NP-4582.
6. *Electrochemical Studies of Microbiologically Influenced Corrosion*. EPRI, Palo Alto, CA: 1991. NP-7468.
7. *Nondestructive Evaluation: Buried Pipe NDE Reference Guide–Revision 2*. EPRI, Palo Alto, CA. Product ID: 1025220.
8. *Nondestructive Evaluation: Buried Pipe In-Line NDE Depth Sizing Procedure*. EPRI, Palo Alto, CA. Product ID: 1025231.
9. *EPRI's Intermediate Diameter Buried Piping Instrumented Vehicle – Evaluation*. EPRI, Palo Alto, CA. Product ID: 1022926.
10. *Buried Pipe Guided Wave Examination Reference Document*. EPRI, Palo Alto, CA. Product ID: 1019115.
11. *Nondestructive Evaluation: Buried Pipe Guided Wave Analysis Tools*. EPRI, Palo Alto, CA. Product ID: 3002000466.
12. *Obtaining Credit for Guided Wave as a Buried Pipe Direct Examination*. EPRI, Palo Alto, CA. Product ID: 3002000468.
13. Nuclear Regulatory Commission, LR-ISG-2012-02, Aging Management of Internal Surfaces, Fire Water Systems, Atmospheric Storage Tanks, and Corrosion Under Insulation.
14. NACE International, Paper No. 2242, Mitigating Soil-Side Corrosion on Crude Oil Tank Bottoms Using Volatile Corrosion Inhibitors, Corrosion 2013.

15. Nuclear Regulatory Commission, Generic Letter (GL) 89-13, Service Water System Problems Affecting Safety-Related Equipment.

16. TWI, *What are the advantages and disadvantages of eddy current testing?*, 10/3/2013, http://www.twi-global.com/technical-knowledge/faqs/ndt/faq-what-are-the-advantages-and-disadvantages-of-eddy-current-testing/

Appendix A: 2013 Industry Survey

In 2013, EPRI conducted a survey on corrosion and CP related issues for BOP SSCs. The objective of this survey was to:

- Determine if there are corrosion issues at nuclear plants with concrete structures, tanks, heat exchangers, condensers, intake structures, concrete piping, and other SSCs.
- Obtain information on which SSCs are protected with CP and assess effectiveness of the protection.
- Identify R&D needs such as guidelines for improving existing CP systems and implementing other corrosion control measures.

Eleven responses from the US and Canada were received. One of the survey responses was incomplete, and therefore excluded from analysis. The following was ascertained by EPRI from the survey responses:

- There are some corrosion issues in the BOP, particularly for coastal plants.
- The condition of many SSCs was reported as being "unknown".
- Most SSCs, if applicable, are not protected from corrosion through the application of CP.

Results of the 2013 survey were revisited as part of this project to identify trends and assist in the development of a 2014 industry survey which was eventually conducted in support of this project. During the analysis generic groupings were used to better categorize limited survey responses. Table A-1 provides an overview of individual components and generic grouping assignments.

After grouping, the total number of survey responses remained small. As such, care is necessary when identifying perceived trends, which may be the result of responses from only a single survey participant. Such anomalies in survey response trends are identified, to the extent possible, in the following sections. One such example is "wetwells", otherwise known as suppression pools, which were addressed by only one survey participant and were therefore excluded from the following analysis.

Table A-1
Generic Component Groupings

Survey Components	Generic Grouping
Auxiliary Building (reinforcing steel)	Concrete Reinforcement
Component Cooling Water Heat Exchanger	
Concrete Intake Structures (reinforcing steel)	
Concrete Piers (reinforcing steel)	
Concrete Pipe (e.g., reinforcing steel and cylinder of PCCP)	
Concrete Tunnels (reinforcing steel)	
Concrete Vaults (reinforcing steel)	
Condenser Water Boxes	
Containment Buildings (PWRs), Reactor Bldg. (BWRs), (liner, reinforcing steel)	
Refueling Water Storage Tank	
Turbine Building (reinforcing steel)	
Cooling Towers	
Building Penetrations	Structural Steel
Steel Pilings	
Tower Guy Anchors	
Diesel Oil Tank	Tank
Lube Oil Tank	
Make-up Water Tank	
Other - Fire Water Storage	
Other - Spray Pond Wall Reinforcing Steel	
Other - Waste Neutralizing, Demineralized Water, Fire Protection Water, Liquid Radiation Waste, and Oily Water Separator Tanks	
Trash Racks, Traveling Screens	Trash Racks, Traveling Screens

A.1 Survey Analysis

Figure A-1 contains survey responses regarding equipment categories which have experienced corrosion.

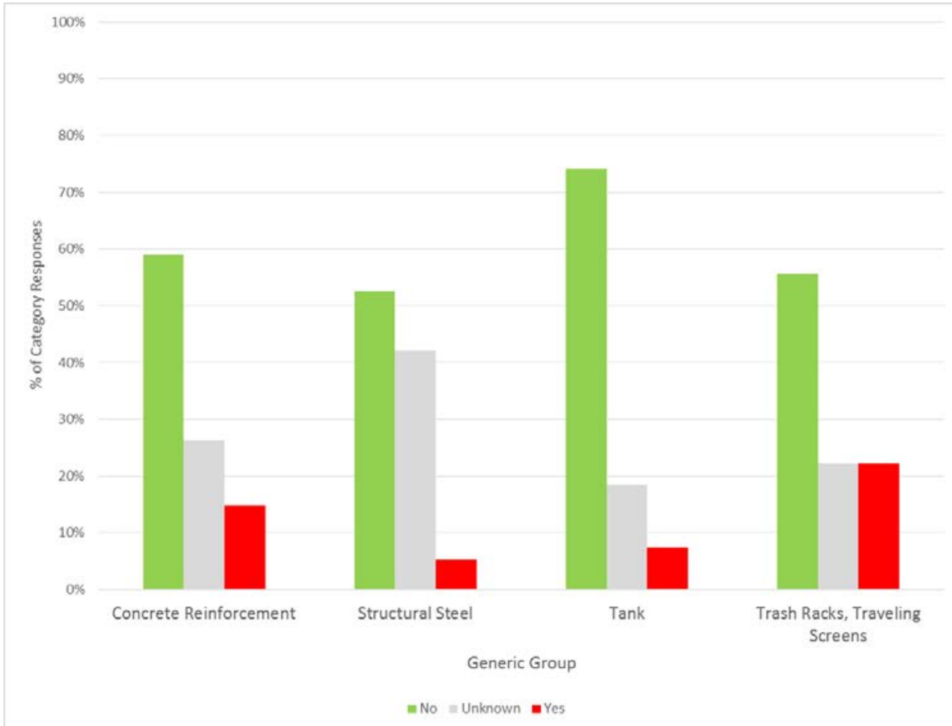

Figure A-1
Equipment Groups Experiencing Corrosion

It was observed that all equipment groups are reported to have experienced some level of corrosion. The Trash Rack, Traveling Screens group received the greatest percentage of survey responses related to corrosion experience. The exact factors influencing the percentage of survey responses relative to this group could not be ascertained from the survey results. However, the wet/dry cycles associated with the operation of these components can create an aggressive corrosion environment. Survey results indicate corrosion of Trash Rack, Traveling Screens, and effective mitigations strategies is an area where additional research may benefit BOP reliability.

It can also be observed that a high level of "Unknown" responses were received for all equipment groups. The Structural Steel group received the greatest percentage of "Unknown" survey responses. The high level of "Unknown" responses represents an area where additional research may be beneficial for determining whether the high number of "Unknown" responses is due to a lack of inspections or is representative of a knowledge gap regarding plant OE.

The history of corrosion was further analyzed based on plant location. Plants which are located within 30 miles of a coast were categorized into a "Coastal" group due to the unique corrosion environment. The remaining plants were categorized as "Inland." Figure A-2 contains a comparison of corrosion history based on proximity to the coast.

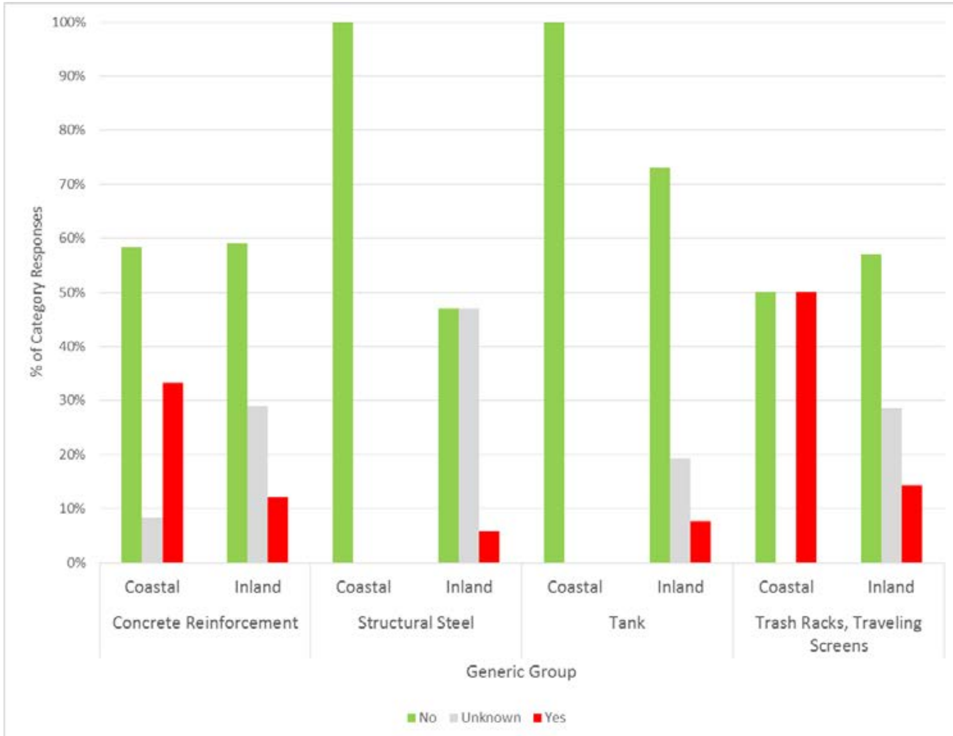

Figure A-2
Equipment Groups Experiencing Corrosion Based on Coastal Proximity

The ability to compare survey results for coastal and inland plant locations is limited due to a skew in the survey respondents (2 coastal, 8 inland). Therefore, only a relative comparison of degraded components can be conducted. Based on a relative comparison, it was observed that a clear correlation between coastal proximity and component groups cannot be obtained.

Survey participants were also asked whether or not CP was used to mitigate the threat of corrosion for each component contained in the survey. Figure A-3 provides an overview of survey responses considering the division based on location.

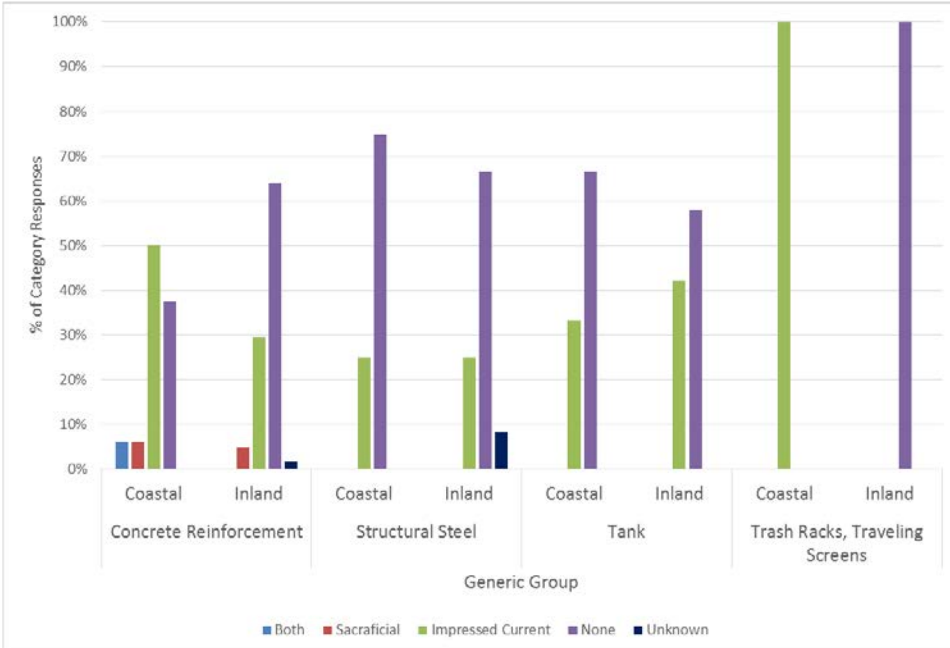

Figure A-3
Equipment Groups Designed with Cathodic Protection

The majority of survey participants indicated CP was not used to mitigate the threat of corrosion. When CP systems are used, the majority of responses indicated the use of an impressed current CP system.

It is common for a CP system to be installed but to be in a non-functional state. In a non-functional state, CP systems do not assist in corrosion mitigation. As such, survey participants were asked if installed CP systems are in operation. The results of this survey question are provided in Figure A-4.

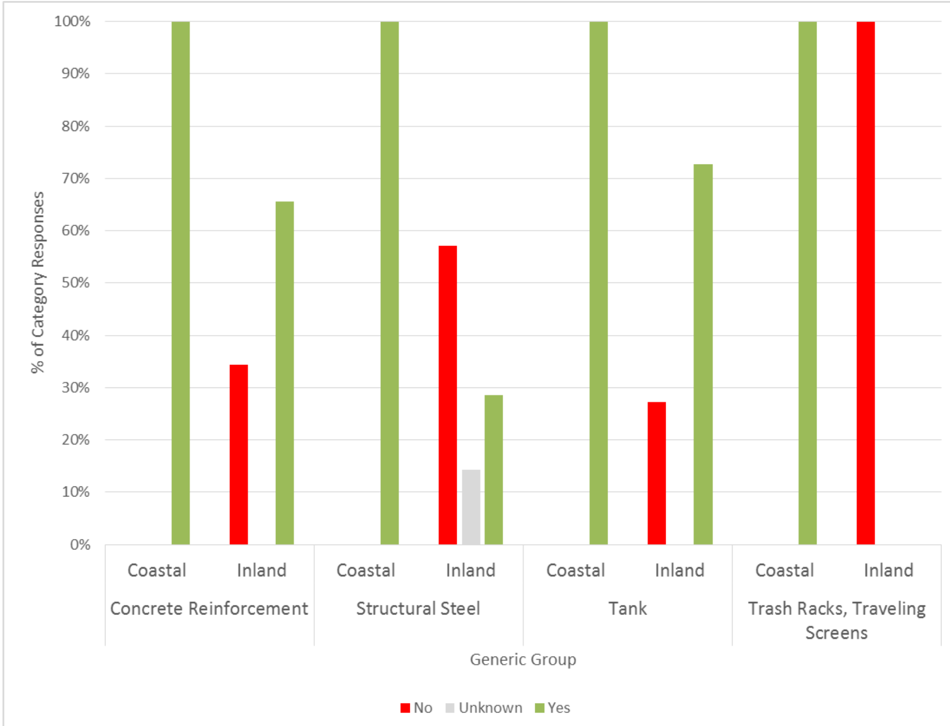

Figure A-4
Equipment Groups with Operating Cathodic Protection

Survey responses from plants located near the coast reported unanimously that CP systems are maintained in an operational state. Survey responses from plants located inland were less consistent with about half reporting an operational CP system. This variation in survey responses may be influenced by the quantity of coastal versus inland plants which responded.

Simply having a CP system installed and operational is often viewed as a sufficient means of corrosion mitigation. However, it is important to provide the appropriate level of protection to effectively mitigate the threat of corrosion. Figure A-5 provides a summary of survey responses when asked if applied CP is effective.

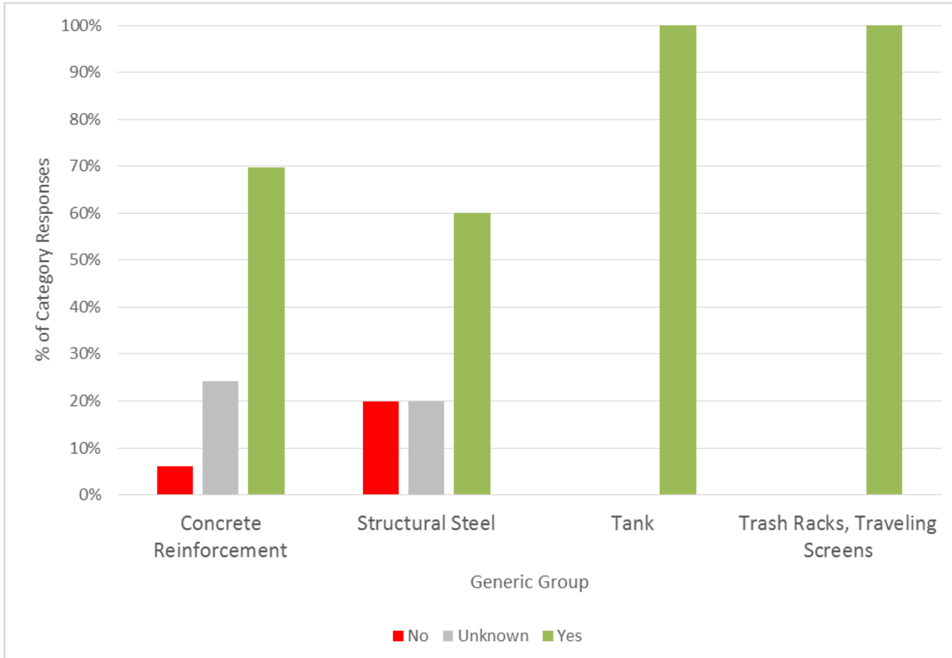

Figure A-5
Equipment Groups with Effective Cathodic Protection

Survey responses from all plants indicated CP systems are generally considered to be effective. While this is a positive industry trend, the survey did not define a criteria for assessment of CP system effectiveness. Simply having an operating CP system may not be sufficient enough to provide adequate levels of corrosion control as anodes deplete throughout the service life.

A.2 Observations

Two primary observations were drawn from analysis of the EPRI survey results for consideration during the 2014 industry survey development. Those observations include:

- Survey population size and diversity have a significant influence on the ability to identify meaningful industry trends. As such, the 2014 industry survey was structured and deployed in a format that encourages participation by a diverse population.
- The EPRI survey focused on whether or not CP was being used to protect plant SSCs. Such CP systems are generally designed to provide protection for a period of 20-30 years. As nuclear power plant operators explore 40-80 years of plant operation, it is important to periodically replenish CP systems. Results of the EPRI survey did not include information to determine if and how plants are addressing the depletion and restoration of aging CP systems. As such, the 2014 industry survey investigates how CP systems are being managed.

Appendix B: 2014 Industry Survey

In 2013, EPRI conducted an industry survey to develop an initial, high level, understanding of the current corrosion state of BOP SSCs and the application of CP for corrosion mitigation. Subsequent to the 2013 industry survey, an industry assessment was performed to better understand the current corrosion state of BOP SSCs. The statement of work included the following areas of interest:

- Identification of important BOP structures and equipment
- Relevant plant operating experience
- Plant responsibilities
- Applicable corrosion control programs and commitments
- Condition assessment technologies being used
- Results from inspections
- Corrosion mitigation practices being employed

During the execution of this project, a second industry survey (referred to as the 2014 industry survey) was developed to assist in addressing these areas of interest. The 2014 industry survey included a total of 23 questions covering the following categories:

- General Corrosion – Questions intended to categorize: components that are most frequently found degraded, common degradation mechanisms, and implemented mitigation strategies without consideration of component type.
- Buried and Aboveground Tanks – Questions intended to identify degradation mechanisms, inspection techniques, and mitigation strategies for BOP tanks used to store diesel fuel oil, radiological waste, and demineralized water.
- Concrete Structures and Piping – Questions intended to identify degradation mechanisms, inspection techniques, and mitigation strategies for BOP concrete components and structures such as intakes, turbine buildings, tower foundations, pre-stressed concrete cylinder pipe (PCCP), and duct banks.
- Heat Exchangers – Questions intended to identify degradation mechanisms, inspection techniques, and mitigation strategies for varying types of BOP heat exchangers such as component cooling water heat exchanger, main condenser, feedwater heaters, and condenser water boxes.

- Large Metallic Plant Components or Structures – Questions intended to identify degradation mechanisms, inspection techniques, and mitigation strategies for BOP metallic components which do not fit into the previous categories such as traveling screens, trash racks, turbine building superstructure, and pipe supports.

The 2014 industry survey questions sought to gain understanding of the current state of corrosion for each equipment category. This included the identification of degradation mechanisms, inspection techniques, and mitigation strategies associated with BOP SSCs. Survey participation and results for each SSC category for the 2014 industry survey are discussed in the following sections.

B.1 Participation

The 2014 industry survey was strategically designed and deployed to encourage survey participation and obtain responses from a diverse population (i.e., coastal/inland, BWR/PWR/PHWR, etc.). In total, 42 respondents representing 34 sites with a total of 54 units from throughout the United States and Canada participated in the 2014 industry survey. Figure B-1 provides a geographic representation of the survey responses with sites in RED indicating a survey response. The number of respondents covers approximately 50% of all sites located in the United States and Canada.

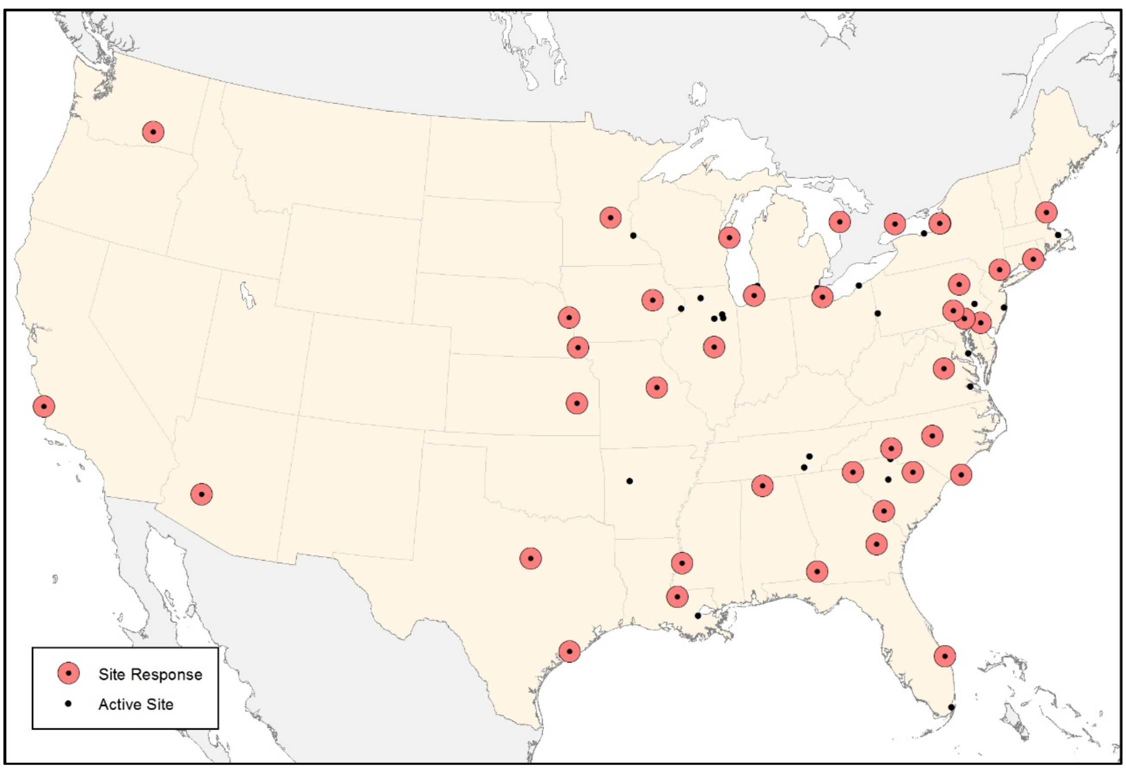

Figure B-1
Geographic Location of Plant Responses for Survey

Survey responses were received from plants representing a mix of attributes such as coastal/inland, north/south, PWR/BWR/PHWR, concrete designs, and age. Figure B-2 and Figure B-3 provide an overview of survey participation by coastal proximity and plant type, respectively.

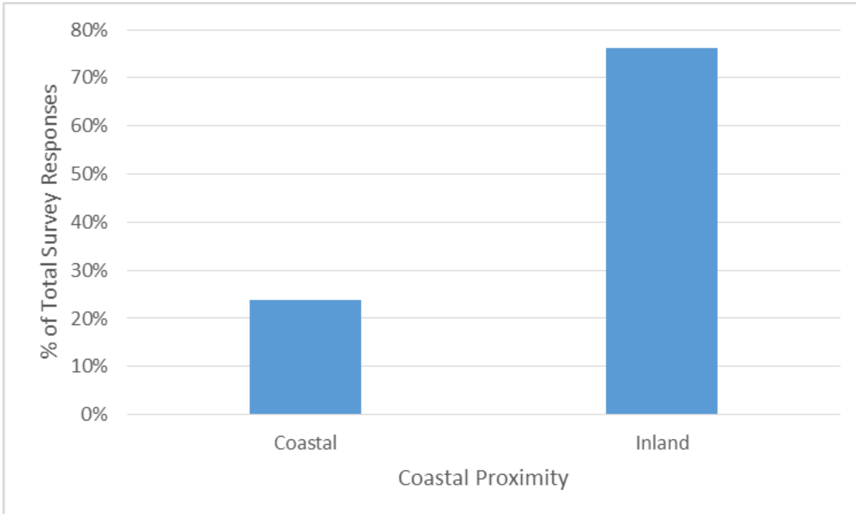

Figure B-2
Survey Responses by Coastal Proximity

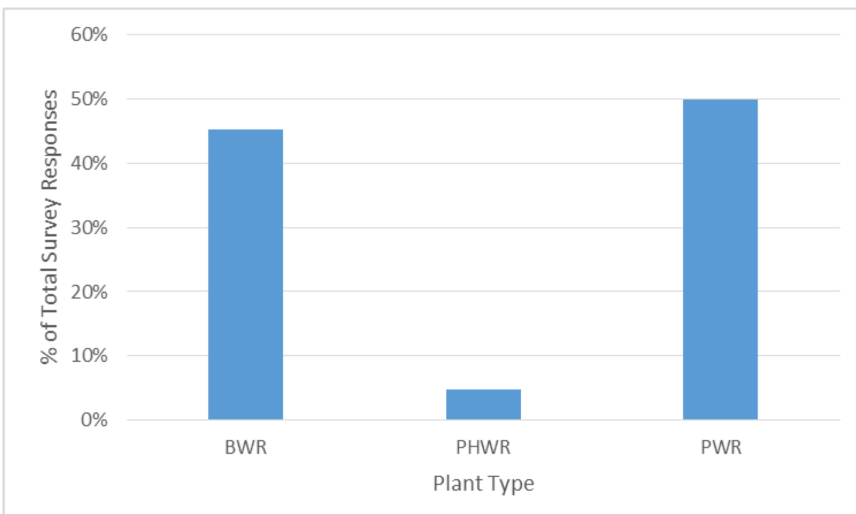

Figure B-3
Survey Responses by Plant Type

The distribution of geographic plant locations and reactor designs is considered representative of the North American nuclear industry and the interpretation of results should be applicable to all sites. It is also notable that while only three major plant types were included in the survey, a variety of reactor vendors were involved in the construction of these plants. Figure B-4 provides a spatial overview of plants by reactor vendor and plant type.

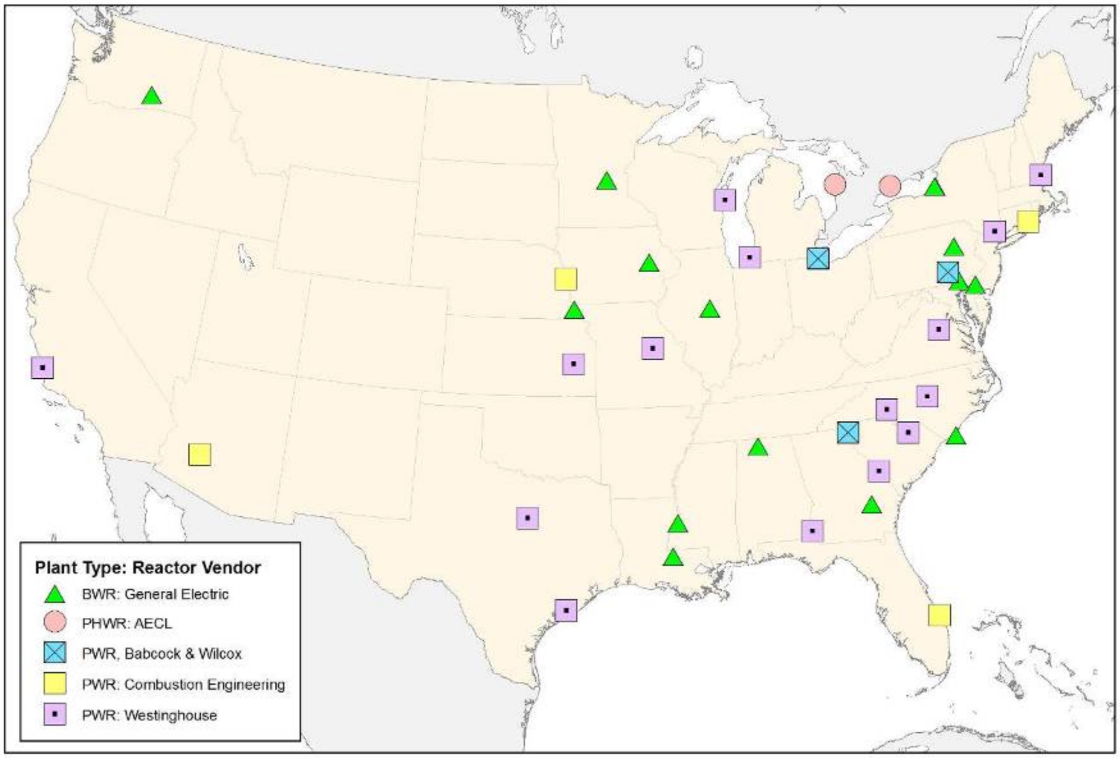

Figure B-4
Survey Responses by Reactor Vendor and Plant Type

It was recognized during survey development that a diverse population of respondents is needed to draw conclusions with broad applicability to the industry as a whole. However, designing a survey, which captures all aspects of plant operating experience (OE) was not feasible. Therefore, to gain a better understanding of industry needs, the 2014 industry survey requested additional information from utility participants. Additional information was provided by industry participants through subsequent interviews. The interviews provided information about plant responsibilities, program commitments, and ascertained specific operating experience regarding BOP SSCs at their respective sites. Figure B-5 provides an overview of the ten (10) sites which participated in follow up interviews.

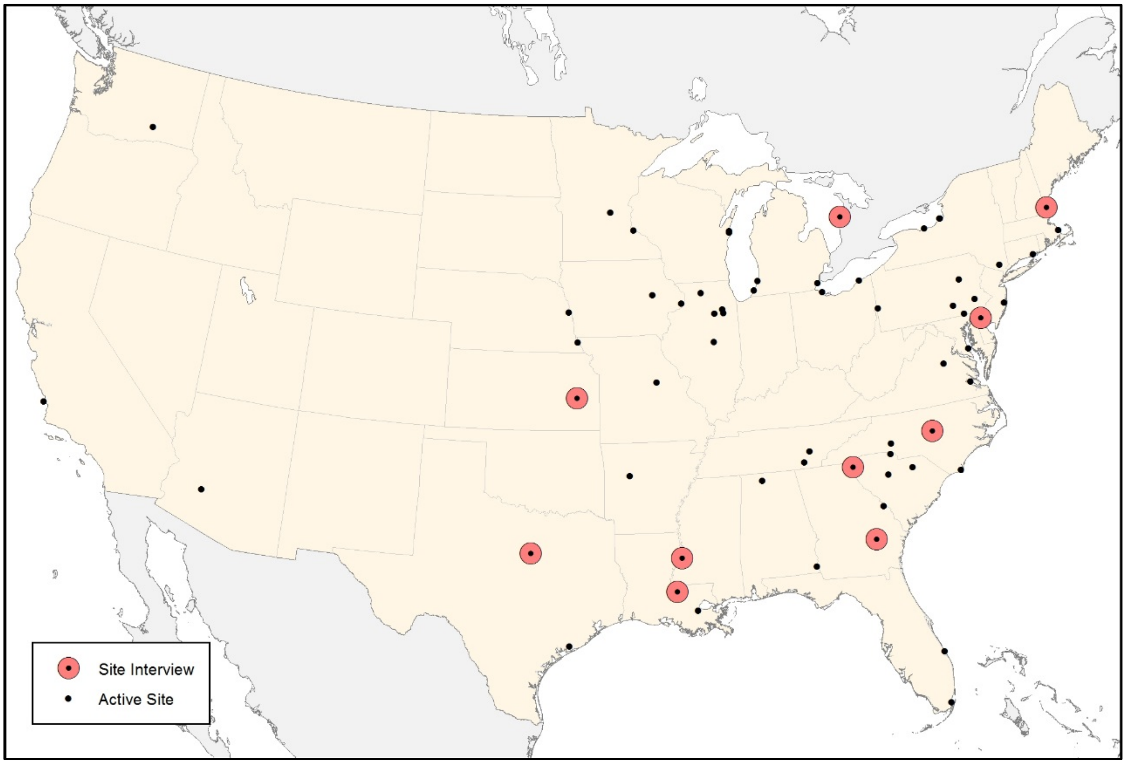

Figure B-5
Geographic Location of Plant Interview Participants

Diversity of the 2014 industry survey participants was maintained in plant interview participation. However, one significant deviation exists between the 2014 industry survey and interview participant population. Plant interview participants did not include representation from any plants located in the western United States. Overall, it was determined both the 2014 industry survey and plant interviews maintained sufficient diversity for meaningful analysis.

B.2 Survey Analysis

Results of the survey questions are discussed in the body of this document. The remaining sections of this appendix contains an analysis of survey results for the individual equipment categories. Each analysis is organized in the following format:

- <u>Introduction</u> – A basic outline of the equipment category and background information
- <u>Degradation Mechanisms</u> – Discussion of the most frequently observed degradation mechanisms
- <u>Inspection Techniques</u> – Discussion of the most commonly implemented inspection techniques and which techniques were considered effective by participants

- Mitigation Strategies – Discussion of the most commonly implemented mitigation strategies and which techniques were considered effective by participants
- Related Discussion – Discussion of survey results and any observations

Areas where additional research may benefit BOP reliability are identified by sentences which contains "*Additional Research*".

B.3 Buried and Aboveground Storage Tanks

This category included tanks containing any type of fluid including, but not limited to: fuel oil, raw water, radiological waste, and treated water. These tanks that were constructed from a variety of materials, varying by site, including carbon steel, stainless steel, and aluminum.

Plant responsibilities for aging management of tanks is commonly driven by scheduled preventative maintenance (PM) programs. The basis for PM actions varies but may include actions associated with specific documents developed from strategic initiatives such as NEI 07-07 or NEI 09-14. In addition to plant specific programs, some one-time or periodic internal inspections are completed at the request of outside organizations, such as American Nuclear Insurers (ANI), due to inherent risk associated with operation of an individual tank. Many tanks also receive routine external visual examinations as part of normal plant surveillance.

B.3.1 Degradation Mechanisms

Figure B-6 contains results of survey questions for degradation mechanisms, which have been identified.

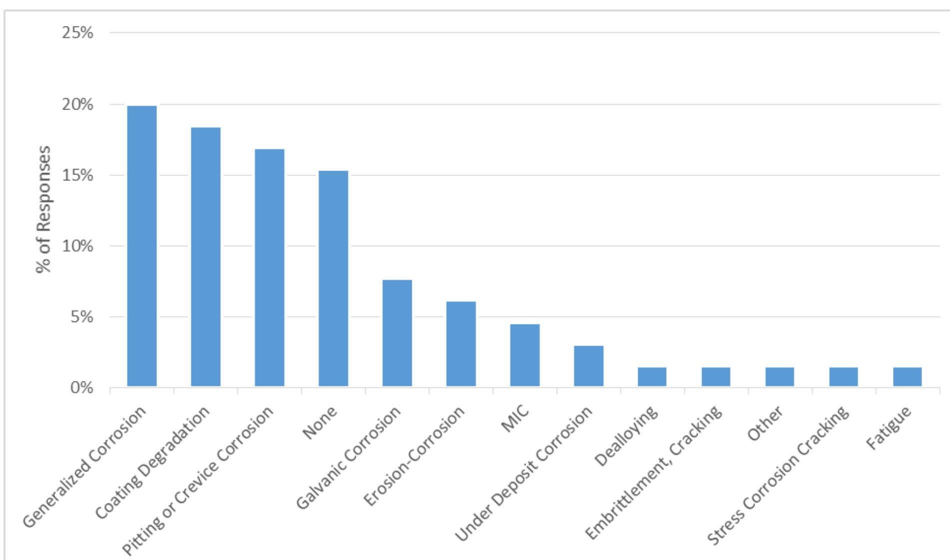

Figure B-6
Degradation Mechanisms Experienced, Tanks

Survey responses indicated the top three degradation mechanisms include generalized corrosion, coating degradation, and pitting or crevice corrosion. While 15% of the survey population indicated no degradation has occurred, over 50% indicated various types of corrosion have been observed.

In addition to a global review, survey responses were analyzed based on coastal/non-coastal environments and plant type to see if any trends exist in the type of degradation mechanisms identified. Results of this analysis indicate little to no significant variation in survey results based on coastal/non-coastal environments or plant type.

B.3.2 Inspection Techniques

Figure B-7 contains inspection techniques which have been used by survey participants.

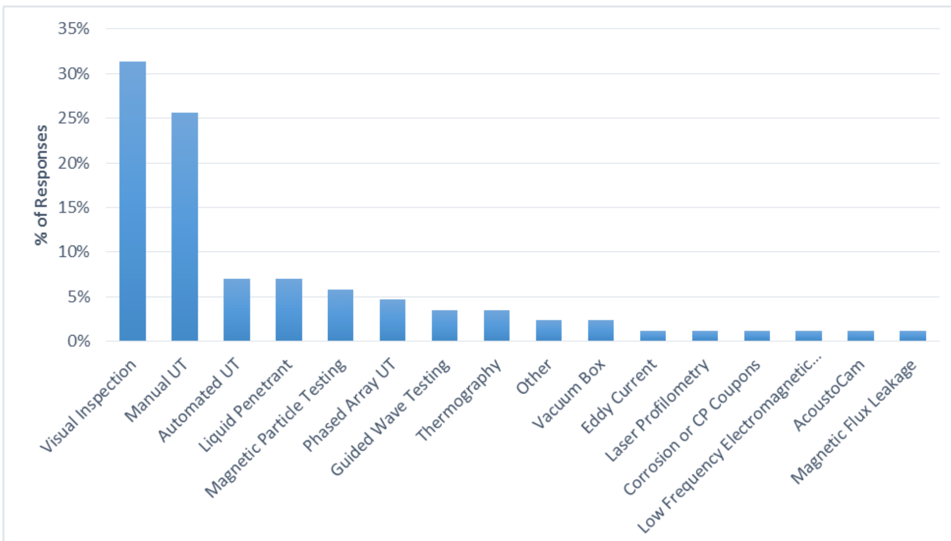

Figure B-7
Inspection Techniques, Tanks

Approximately 37% and 31% of survey participants indicate the use of UT technologies (i.e., manual, automated, or phased array) and visual inspection. The combination of UT technologies and visual inspections represents the majority of inspection techniques employed by survey participants. In addition to asking which inspection techniques have been used for tanks, survey participants were asked which techniques were effective. Survey responses regarding effective inspection techniques for tanks are provided in Figure B-8.

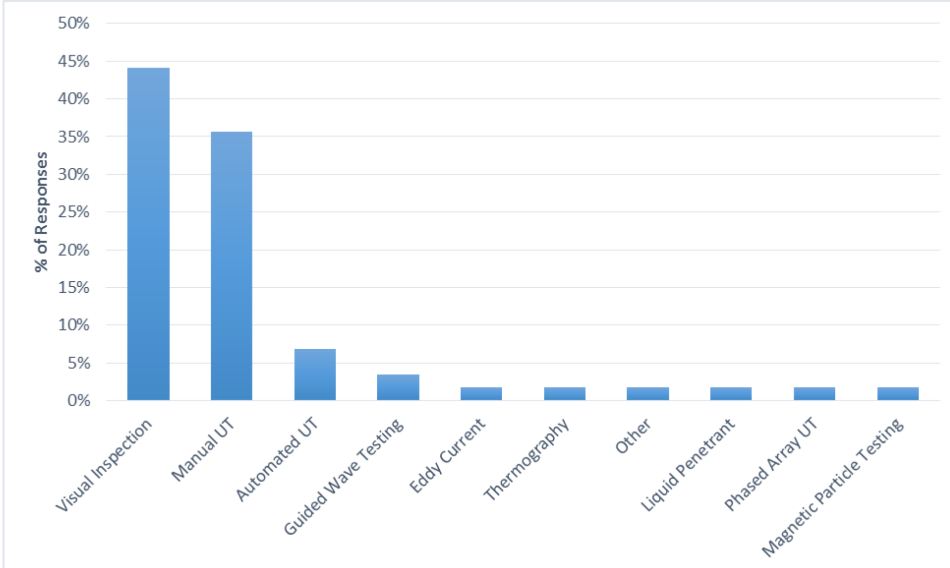

Figure B-8
Effective Inspection Techniques, Tanks

The majority of survey participants indicated Visual and UT technologies are viewed as effective methods for tank inspections. The combination of Visual and UT technologies represented 89% of survey responses. This indicates utilities have tried a variety of inspection techniques but tend to default to Visual and UT inspection technologies. A specific reason for this tendency could not be ascertained from the survey data.

B.3.2 Mitigation Strategies

Proactive implementation of mitigation strategies can significantly extend component life when a known degradation threat exists. During the survey, participants were asked which mitigation strategies have been implemented at their site. Figure B-9 contains the results of this survey question.

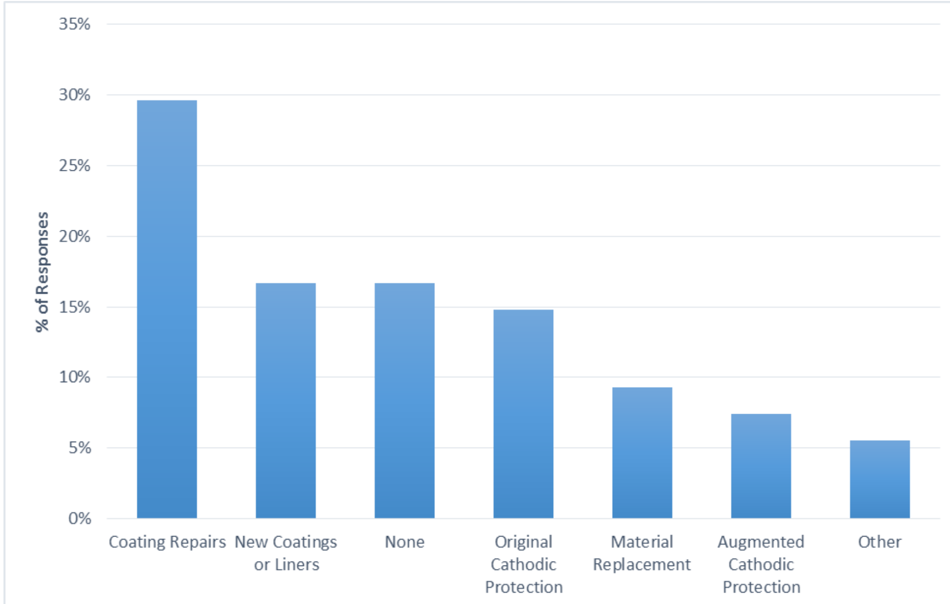

Figure B-9
Mitigation Strategies, Tanks

Mitigation strategies included for tanks can be categorized as: coatings, CP, material replacement, and other/do nothing. The distribution of survey responses for each category are: 47% coatings, 22% CP, 9% material replacement, and 22% other/do nothing. These survey results indicated a strong preference among respondents to implement coatings as a mitigation strategies to protect the existing structure.

While the preferred application of coatings is often the most economical, it may not prove effective for all applications. The most valuable indication of mitigation strategy effectiveness is gained through OE developed as various mitigation strategies are implemented over time. The course of future mitigation can be significantly altered based on OE from previous installations. As a result, survey participants were asked to not only provide previously implemented strategies, but also which of those strategies was perceived as effective. Figure B-10 contains results of this survey question.

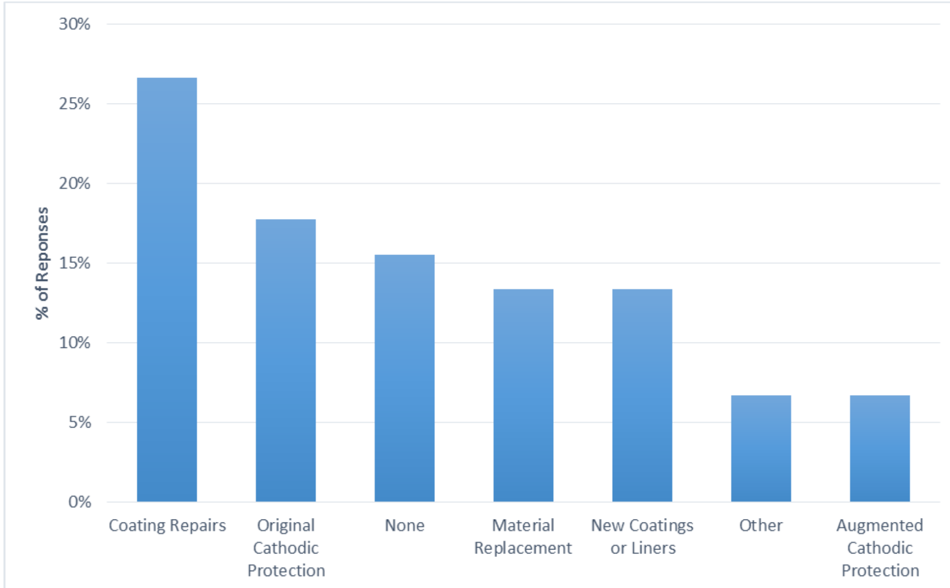

Figure B-10
Effective Mitigation Strategies, Tanks

The distribution of survey responses to the effectiveness of each category, detailed above, were: 40% coatings, 25% CP, 13% material replacement, and 23% other/do nothing. These results indicate the majority of respondents have not only implemented coatings as a mitigation strategy, but also view them as effective. There was, however, a small decrease in the overall percentage of responses indicating coatings were an effective mitigation strategy. This resulted in a greater percentage of the survey population indicating CP and material replacement have been effective. Such shift in survey results is an indication that coatings are generally effective, but may not be sufficient under specific conditions.

B.3.3 Related Discussions

Robust visual inspection programs are generally in place for identifying applicable degradation mechanisms for tanks. The use of visual inspection techniques to inspect tanks has considerable advantages over other NDE relative to cost, resource requirements, execution time, and radiological exposure, where applicable. However, the ability to detect some degradation mechanisms and quantitatively document and assess anomalies through visual inspection is limited. In particular, no information is available for possible degradation occurring on the opposite surface (ID or OD) of the material from where the visual inspection was conducted.

Supplementing visual inspection with other quantitative NDE such as Manual UT, the second most used inspection technique, provides a more comprehensive understanding of the corrosion threat. Unfortunately, Manual UT offers a low number of samples given the overall surface areas in a tank, thereby yielding a more qualitative rather than quantitative assessment. Increasing the number of sample measured will improve reliability but at the expense of cost and time. Also, the ability of manual straight-beam UT to detect changes can be limited in areas with complex geometries such as joints. Alternate automated, semi-automated, and angle beam UT inspection methods may be needed based on the degradation method.

A recent interim staff guidance (ISG) [13], issued by the NRC, recommended the addition of stress corrosion cracking (SCC) as an aging effect requiring management (AERM) for stainless and aluminum tanks. The impact of this additional guidance on inspection findings was uncertain due to limited survey responses indicating SCC has been observed. The low number of responses indicating SCC may indicate sites: (1) do not have tanks constructed of materials susceptible to SCC or (2) inspection techniques are not capable of detecting SCC. *Additional Research* on the appropriate selection of inspection techniques for the detection of known degradation mechanisms (such as SCC), informed selection of inspection locations, and online condition monitoring are areas where BOP reliability may be enhanced to ensure detection of applicable degradation mechanisms.

The majority of survey responses on effective mitigation strategies for tanks are distributed across four major categories. Diversity in mitigation strategies indicates utilities are taking a balanced approach to corrosion mitigation or the corrosive environment can be effectively mitigated through a variety of methods. Based on survey results and subsequent interviews, there are two CP related areas that *Additional Research* may benefit BOP reliability. The two areas are CP system aging (i.e., degrading effectiveness) and injection of corrosion inhibitors.

A number of survey participants indicated the threat of corrosion is mitigated through the use of the original CP system, installed early in plant life. As nuclear power plants age, CP systems designed to protect plant components become less effective until they eventually reach the end of useful life, generally 20-30 years depending on the design. Many of the nuclear power plants located in the US and Canada are nearing the original design life of typical CP systems. Therefore, the importance of monitoring CP system effectiveness is becoming increasingly important.

Monitoring of CP system effectiveness represents a significant opportunity to improve BOP reliability by ensuring effective corrosion control is maintained. Other industries have developed methods, such as access tubes beneath a tank, to support CP system monitoring through the measurement of structure-to-soil measurements and the level of polarization at various positions under or along a tank. Installation of access tubes is often completed during original construction but can be retrofit under existing tanks. *Additional Research* into alternative methods for evaluating polarization levels around tanks may benefit BOP reliability.

Similarly, corrosion of tank bottoms can be difficult to detect due to the large surface area across which degradation can occur. Through-wall degradation of tank bottoms can result in unacceptable consequences, particularly for outdoor tanks in contact with soil where undiscovered leaks could create release of hazardous material. A review of other industry, non-nuclear OE found corrosion has been mitigated through injection of volatile corrosion inhibitors into the voids between the sand pad and the underside of the tank bottom to prevent future corrosion [14]. *Additional Research* on the applicability of this mitigation strategy to nuclear power plant tanks may benefit BOP reliability.

B.4 Concrete Structures and Piping

This category includes structures and piping constructed of concrete, such as building and tower foundations, pre-stressed concrete cylinder pipe (PCCP), and duct banks. Plant components contained in this category may be constructed of a combination of conventionally reinforced, pre-stressed, and post-tensioned concrete.

Plant responsibilities for the aging management of structures and piping is commonly driven by scheduled PM programs. The basis for PM actions associated with these structures and piping varies but may include actions associated with specific programs such as a Structural Monitoring Program (SMP) or routine system engineer surveillance activities.

B.4.1 Degradation Mechanisms

Figure B-11 presents the distribution of survey results for degradation mechanisms of concrete experienced at NPPs.

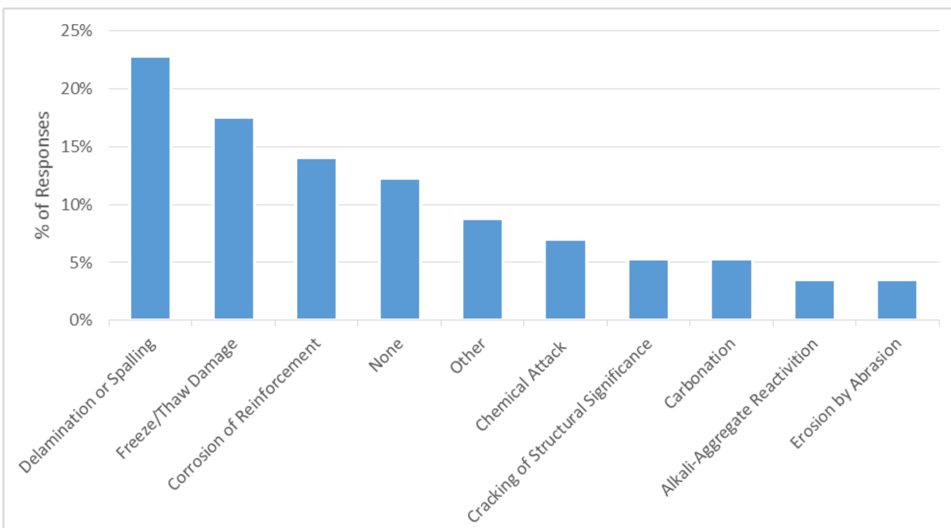

Figure B-11
Degradation Mechanisms Experienced, Concrete

The most reported degradation mechanisms include delamination/spalling, freeze/thaw damage, and corrosion of the reinforcing steel. Analysis indicates little to no significant variation in survey responses based on coastal/non-coastal environments, plant type, or geographical location (northern vs. southern North America).

B.4.2 Inspection Techniques

A variety of inspection techniques are being used to identify degradation and quality issues in concrete components. Figure B-12 contains inspection techniques used by survey participants.

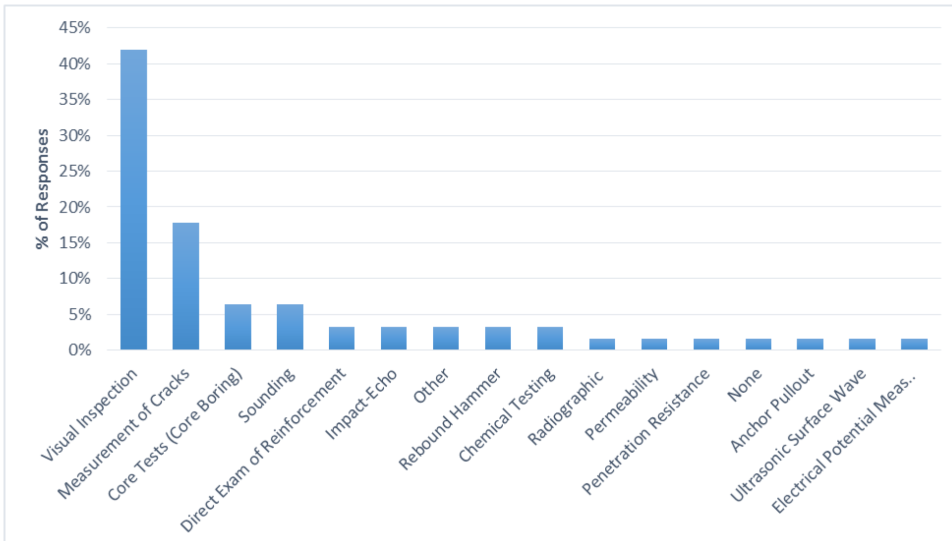

Figure B-12
Inspection Techniques, Concrete

In addition to the previous question asking the inspection techniques for concrete components and structures, survey participants were asked which techniques were effective. Figure B-13 contains the results of this survey question.

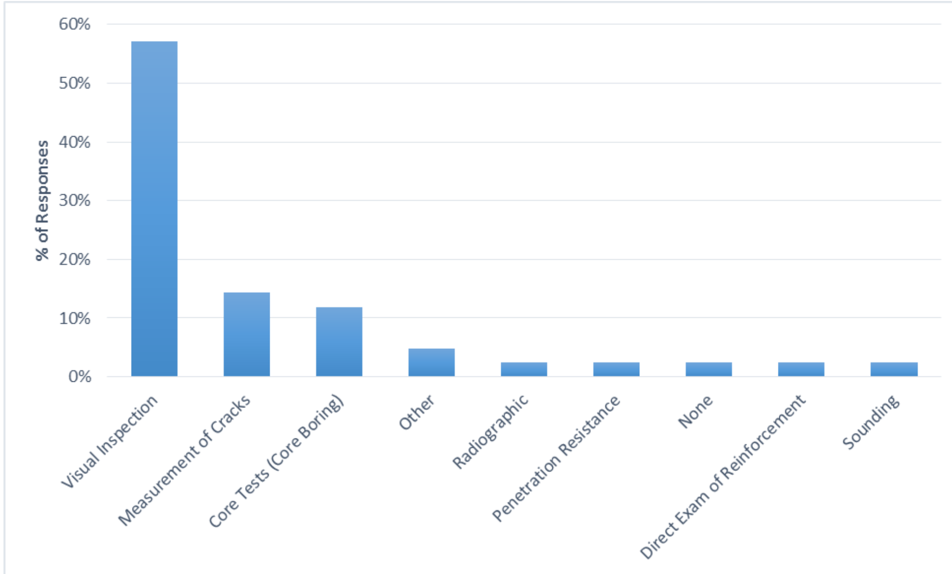

Figure B-13
Effective Inspection Techniques, Concrete

Visual inspection is relied upon as the primary method for inspections of concrete components. It is notable that a broad range of inspection techniques have been used on concrete components and structures; but, a much smaller subset, relative to other SSC categories surveyed, were considered to be effective. Similarly, among the inspection techniques viewed as being effective, visual inspection and crack measurement, do not directly address the threat of reinforcement corrosion. These techniques are used to evaluate conditions which may be the symptom of reinforcement corrosion.

B.4.3 Mitigation Strategies

The integrity of many concrete components, in particular structures, is critical to the continued economic feasibility of a nuclear power plant. Proactive implementation of mitigation strategies can significantly extend component life when a known degradation threat exists. During the survey, participants were asked which mitigation strategies have been implemented at their site. Figure B-14 contains the results of this survey question.

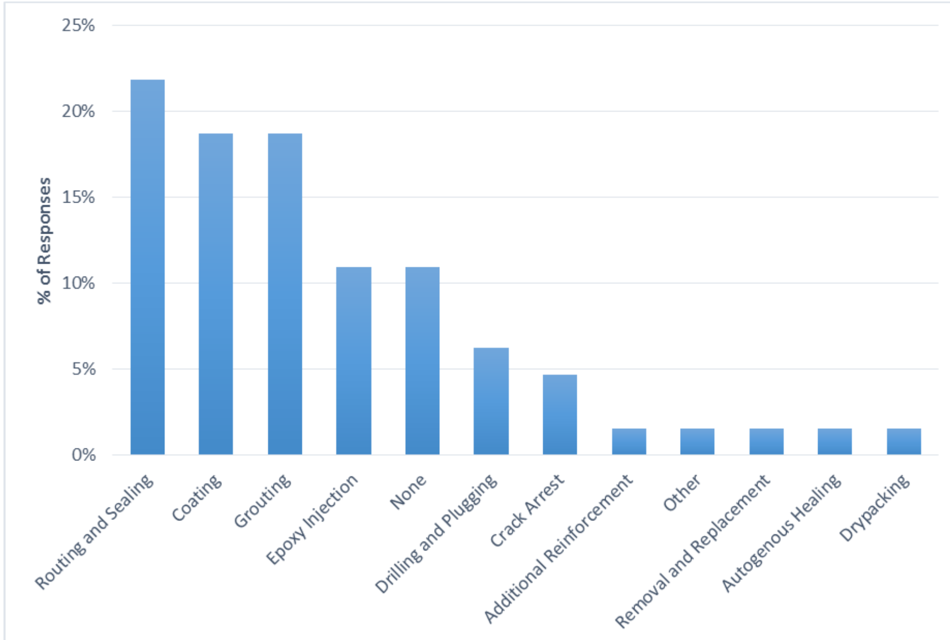

Figure B-14
Mitigation Strategies, Concrete

Some of the most valuable OE gained in the management of aging concrete components occurs as various mitigation strategies are implemented in a plant environment over time. As a result, survey participants were asked which of the mitigation strategies were perceived as effective at their site. Figure B-15 contains results of this survey question.

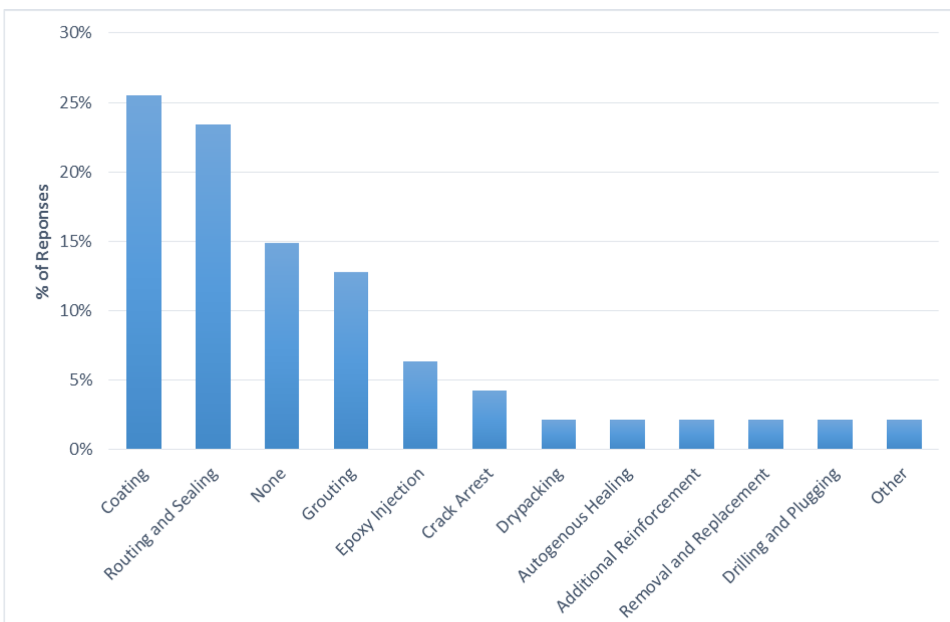

Figure B-15
Effective Mitigation Strategies, Concrete

Survey results indicate grouting/sealing techniques and coatings as the most frequently implemented mitigation strategies. In addition to being the most frequently implemented mitigation strategies, they are also viewed as effective. However, an increase in the percentage of responses viewed sealing techniques (i.e.; coating, routing and sealing) as effective. A reduction in the percentage of responses indicated grouting alone to be effective.

B.4.4 Related Discussions

Structural Monitoring Programs have been implemented at the majority of North American nuclear sites to monitor the condition of structures and provide reasonable assurance that they are capable of performing its intended function. Structural Monitoring Programs are generally focused on structures, which house safety related equipment. However, requirements for structural monitoring are also extended to buildings, which could preclude safety related equipment from performing its intended function.

In many cases, this results in BOP concrete structures being incorporated into structural monitoring programs. This means structures are periodically inspected for signs of degradation. Survey results indicate the majority of such inspections are visual. Visual inspection provides an opportunity to observe degradation of the concrete surface. However, observed surface degradation can be the symptom of other degradation, such as corrosion of the reinforcement. As such, the concept of visual inspection relies heavily on inspector experience to distinguish between minor degradation at the surface and a more extensive degradation mechanism. Years of experience and mentoring generally form the basis for qualification of plant staff to perform structural monitoring. While these are two key components to effective monitoring, written guidance on the monitoring process and documentations are equally important.

Additional Research of the development of acceptance criteria and an inspection checklist may provide benefit and consistency across the fleet.

B.5 Heat Exchangers

This category includes BOP heat exchangers such as Component Cooling Water, Main Condenser, Feedwater Heaters, and Condenser Water Boxes. The quantity of flow and temperature differential between the inlet and outlet of these heat exchangers includes a wide range of performance requirements and corrosion environments.

Plant responsibilities for the management of aging for heat exchangers are often assigned to a heat exchanger program owner responsible for a number of NSSS and BOP heat exchangers. The heat exchanger program owner commonly works with system engineers to identify when degraded heat exchanger heat transfer performance may affect system operation and, subsequently, plant performance.

It was noted that not all sites have a heat exchanger program owner and instead rely on system engineers to ensure systems are available to support reliable plant operations.

Management of BOP heat exchangers aging is also influenced by Generic Letter (GL) 89-13, *Service Water System Problems Affecting Safety-Related Equipment* [15]. Commitments associated with GL89-13 may be managed by heat exchanger program owners, system engineers, or a GL89-13 program owner depending on the utility.

B.5.1 Degradation Mechanisms

Figure B-16 presents the survey responses for degradation mechanisms identified for heat exchangers.

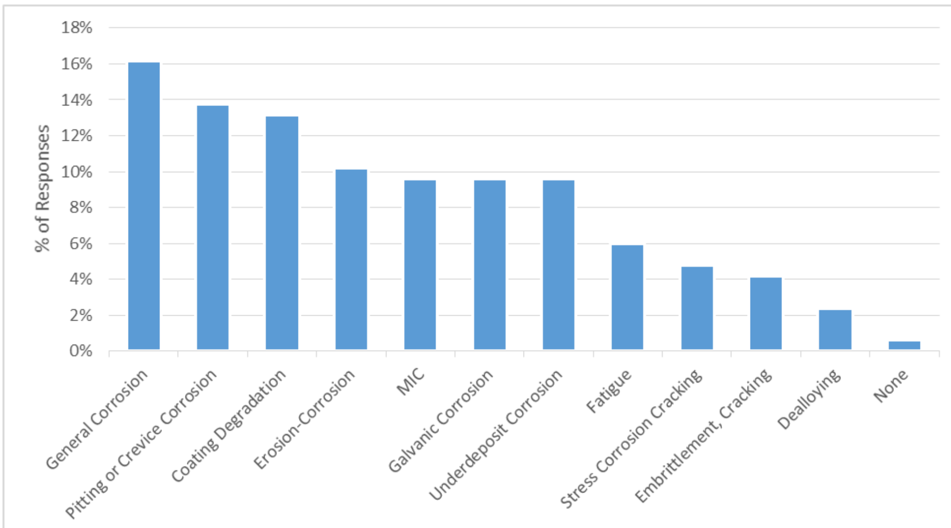

Figure B-16
Degradation Mechanisms Experienced, Heat Exchangers

Survey responses indicated the top three degradation mechanisms include general corrosion, pitting or crevice corrosion, and coating degradation. It is worth noting the smallest number of survey participants indicated an absence of degradation in this survey category which suggests all sites are challenged with heat exchanger degradation in one form or another. Survey responses were also distributed relatively consistently across a range of degradation mechanisms for heat exchangers. This distribution is a deviation from results obtained for other equipment categories included in the survey.

Upon initial review, the wide distribution of degradation mechanisms relative to other equipment categories appears to be a trend indicative of a more significant threat of degradation for heat exchangers. However, it is important to consider the type of inspections completed and level of follow up investigation conducted when degradation is identified. Many inspection techniques are not capable of distinguishing between various degradation mechanisms. In addition, visual inspection of degraded components may result in an incorrect classification of degradation mechanisms. One such example related to MIC requires specialized testing to validate bacteria and positively identify the presence of an active MIC population. In the absence of testing, MIC may be incorrectly categorized into a more generic category, such as pitting or generalized corrosion.

Survey responses indicate little to no significant variation in results based on coastal/non-coastal environments. There was, however, a small variation between the top corrosion mechanisms for BWR and PWR sites. Boiling Water Reactors noted erosion/corrosion and fatigue as the most prevalent degradation mechanisms. Similarly, PWRs indicated general corrosion, pitting or crevice corrosion, and coating degradation as the most prevalent degradation mechanism. While different degradation mechanisms were identified for BWRs and PWRs, the variance appeared to be related to primary knowledge areas of the survey participant rather than difference in plant operations. There was not enough data collected about PHWRs to identify data trends.

B.5.2 Inspection Techniques

A wide range of inspection techniques for heat exchangers, shown in Figure B-17 have been used by survey participants.

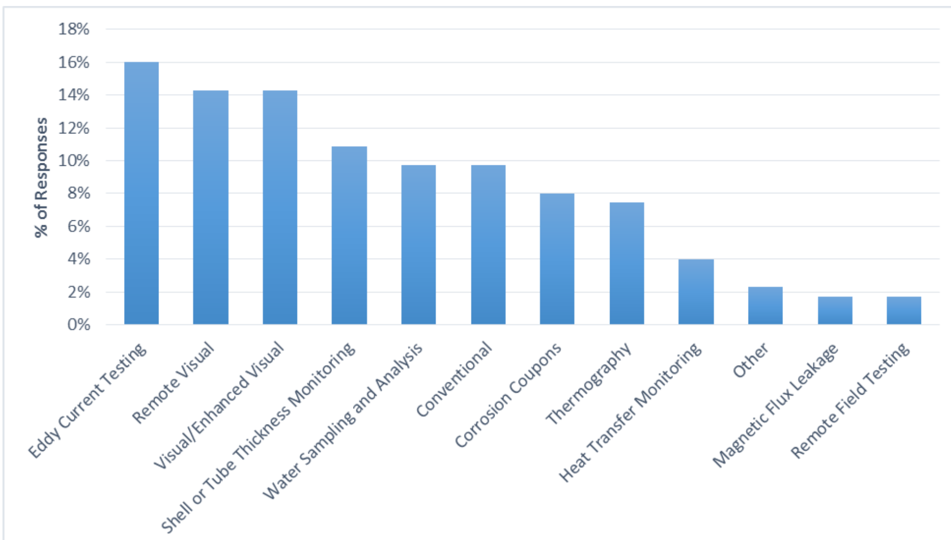

Figure B-17
Inspection Techniques, Heat Exchangers

In addition to the previous question asking the inspection techniques for heat exchangers, survey participants were asked which techniques were effective. Figure B-18 contains the results of this survey question.

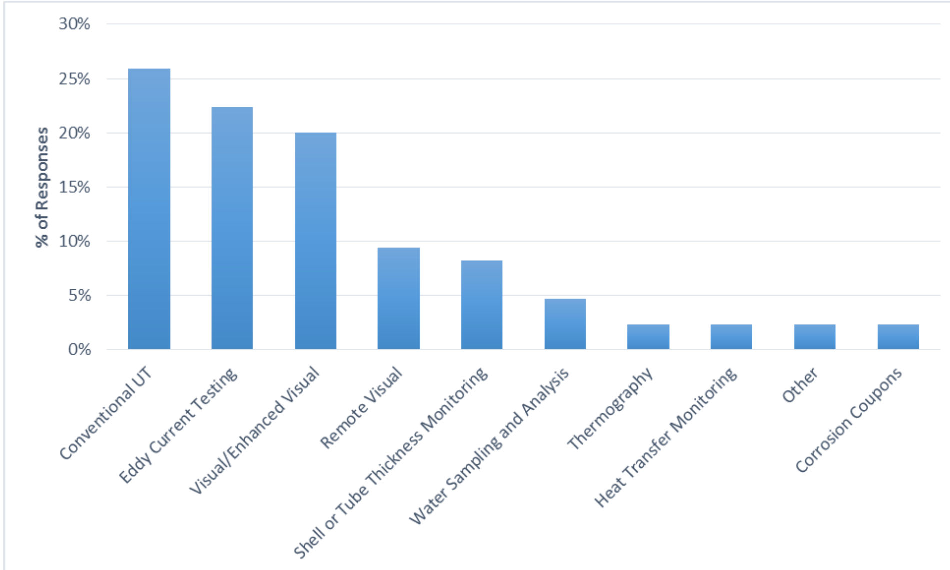

Figure B-18
Effective Inspection Techniques, Heat Exchangers

The survey indicates a wide range of survey techniques are used by plants to monitor the condition of heat exchangers. Many of the inspection techniques used are viewed as effective by survey participants as shown in Figure B-18. The techniques most commonly viewed as effective include visual (including enhanced and remote), conventional UT, and Eddy current testing.

B.5.3 Mitigation Strategies

Proactive implementation of mitigation strategies can significantly extend component life when a known degradation threat exists. Figure B-19 presents the heat exchanger degradation mitigation strategies implemented at sites.

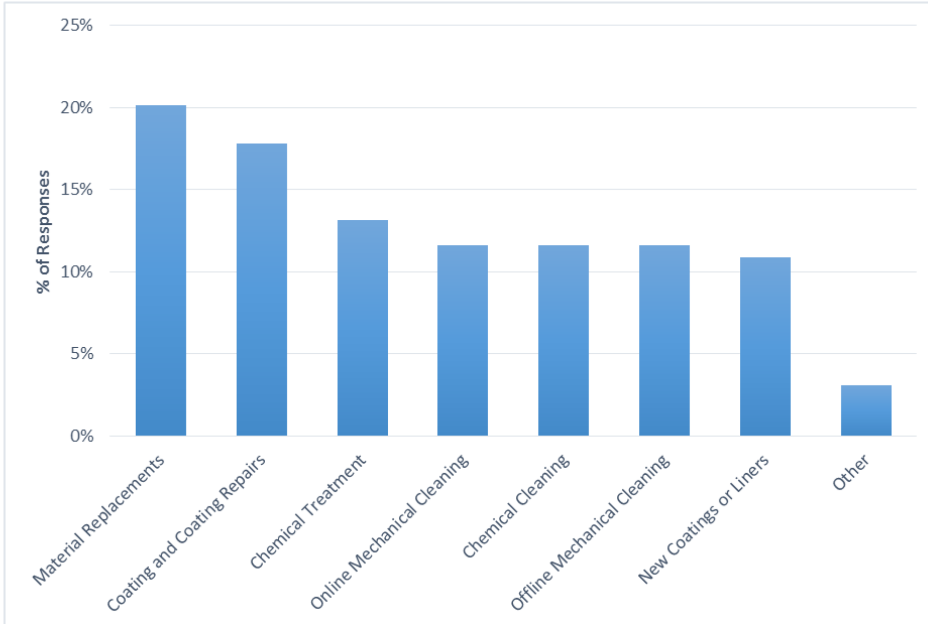

Figure B-19
Mitigation Strategies, Heat Exchangers

Some of the most valuable OE gained in the application of corrosion mitigation strategies occurs as various approaches are implemented in a plant over time. Future mitigation can be significantly altered, based on OE, from previous installations. In addition to the previous question asking the mitigation techniques for heat exchangers, survey participants were asked which techniques were effective. Figure B-20 contains results of this survey question.

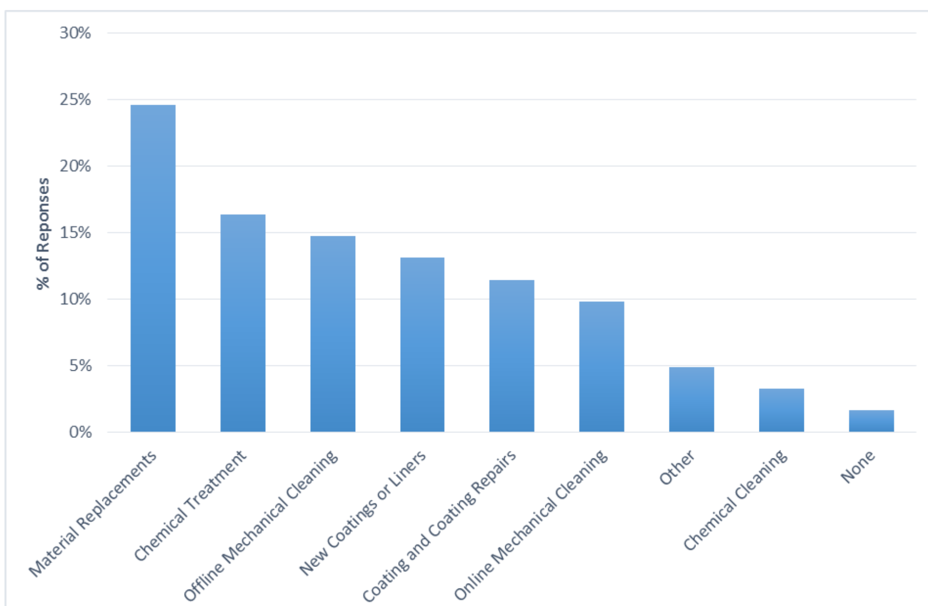

Figure B-20
Effective Mitigation Strategies, Heat Exchangers

Survey results indicate material replacements, coating repairs, and chemical cleaning as the most frequently implemented mitigation strategies. In addition to being the most frequently implemented mitigation strategies, material replacements and chemical cleaning, along with new coatings and mechanical cleanings, were also viewed as effective.

B.5.4 Related Discussions

Sites generally have robust inspection programs in place for identifying applicable heat exchanger degradation through a combination of visual inspection, performance monitoring, Eddy current testing, and UT thickness measurements. Both visual inspection and Eddy current testing allow for rapid inspection of heat exchanger components. However, these inspection techniques have limited applicability for detecting all degradation mechanisms. For example, Eddy current testing does not detect defects parallel to the surface [16] and visual can miss small, inaccessible, or deposit filled anomalies.

Although two of the most commonly used inspection techniques have detection limitations, survey results indicate relatively diverse degradation mechanisms affecting heat exchanger performance. This is an indication that various inspection techniques must be combined as part of effective heat-exchanger inspection programs. In addition, a review of existing literature and phone interviews indicates significant information is available for plant staff to use for heat exchanger aging management. As a result, there are no areas of *Additional Research* recommended related to corrosion of heat exchangers within the context of this project.

B.6 Large Metallic Components and Structures

This category includes BOP metallic components which do not fit into the previous categories such as traveling screens, trash racks, turbine building superstructure, and pipe supports. This is a broad category designed to capture the greatest breadth of plant components possible in the corrosion assessment.

Plant responsibilities for aging management of these components is commonly driven by a combination of scheduled PM programs, system engineer surveillance, and scope expansion based on the identification of other component degradation. The basis for PM actions associated with these components such as traveling water screens is commonly based on plant OE rather than regulatory drivers. Failure of these components result in a need to promptly shut down a unit or reduce power. Both are considered unacceptable actions and thus requires the effects of aging to be managed.

B.6.1 Degradation Mechanisms

Figure B-21 contains the survey responses for degradation mechanisms identified in these large metallic components and structures. Since these components are constructed from similar metallic materials to tanks and piping, the distribution of degradation types reported are similar.

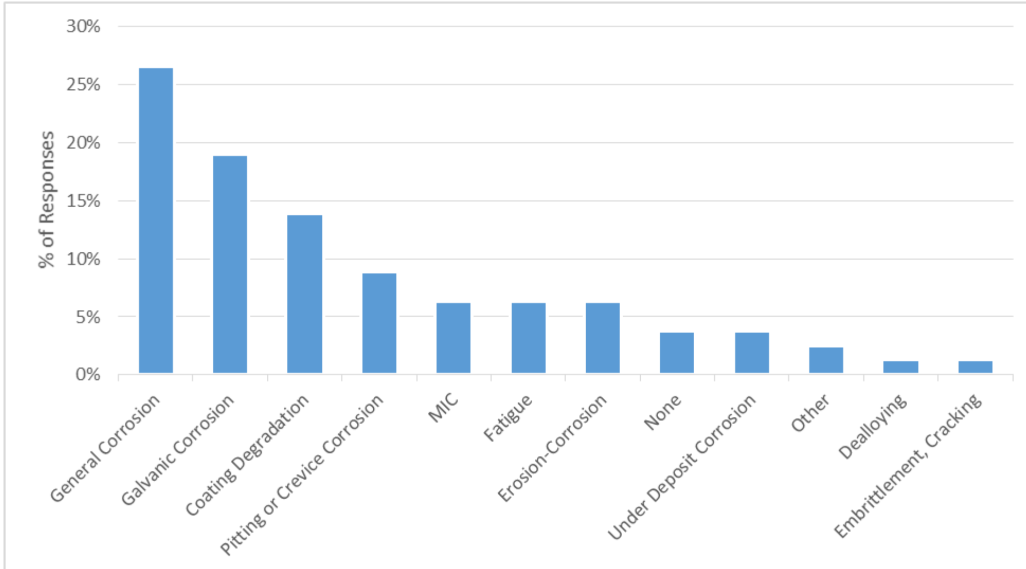

Figure B-21
Degradation Mechanisms Experienced, Large Metallic Components and Structures

Survey responses indicated the top three degradation mechanisms include general corrosion, galvanic corrosion, and coating degradation. In general, the number of survey responses received from inland plants indicate the presence of a more diverse portfolio of degradation mechanisms experienced. However, results of this analysis indicate little to no significant variation in survey results based on plant type.

B.6.2 Inspection Techniques

The inspection methods used to evaluate large metallic components is shown in Figure B-22 and strongly relies on visual inspection with some complimentary UT to gauge remaining thickness or magnetic particle/dye penetrant testing if cracking is anticipated.

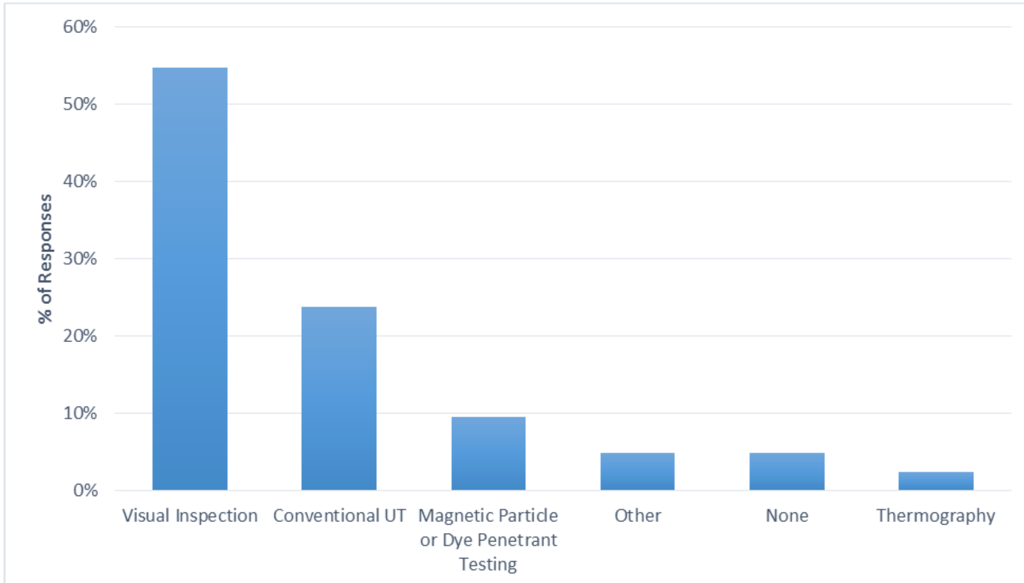

Figure B-22
Inspection Techniques, Large Metallic Components and Structures

In addition to the previous question asking the inspection techniques, survey participants were asked which techniques were effective. Figure B-23 contains the results of this survey question.

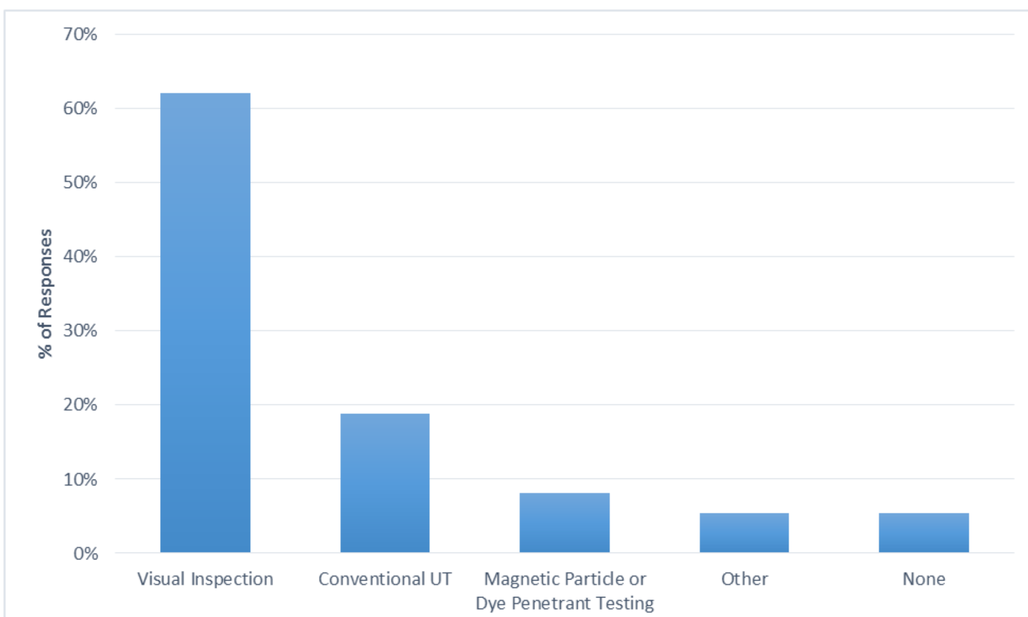

Figure B-23
Effective Inspection Techniques, Large Metallic Components and Structures

The survey indicates less diversity in techniques by plants for monitoring the condition of large metallic structures. Visual examination, conventional UT, and magnetic particle/dye penetrant techniques are the most frequently selected inspection techniques. In addition to being the most frequently implemented inspection techniques, these are also viewed as effective. It is notable that this survey category includes a very diverse set of plant SSCs. Limited distribution of inspection techniques selected may be a result of the equipment categorization approach or accessibility issues limit the implementation of other inspection techniques.

B.6.3 Mitigation Strategies

Proactive implementation of mitigation strategies can significantly extend component life when a known degradation threat exists. As part of the survey, participants were asked which mitigation strategies have been implemented at their site. Figure B-24 contains the results of this survey question.

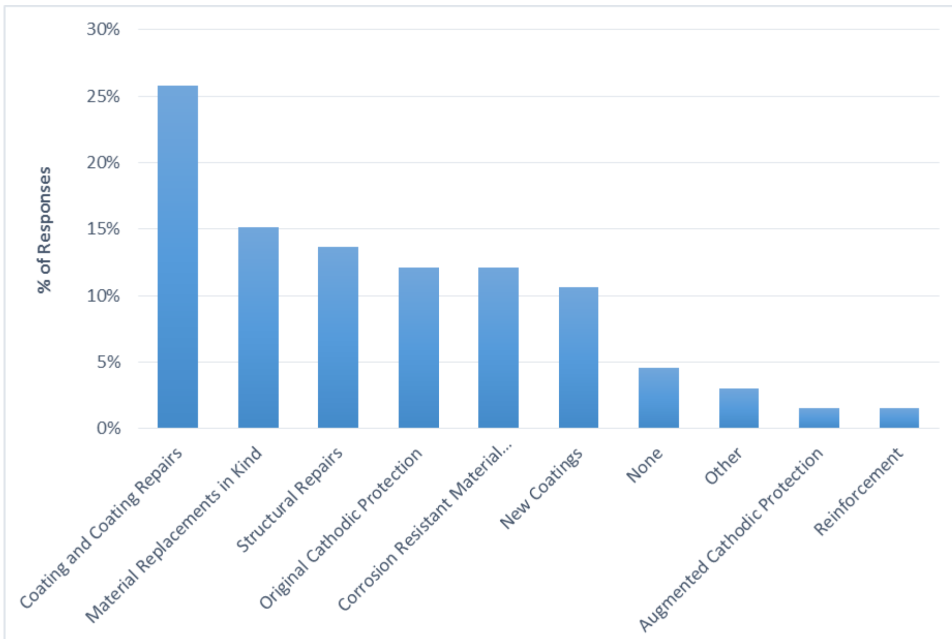

Figure B-24
Mitigation Strategies, Large Metallic Components and Structures

Some of the most valuable OE gained in the application of corrosion mitigation strategies occurs as various approaches are implemented in a plant over time. The course of future mitigation can be significantly altered based on OE from previous installations. In addition to the previous question asking the mitigation techniques for large metallic components and structures, survey participants were asked which techniques were effective. Figure B-25 contains results of this survey question.

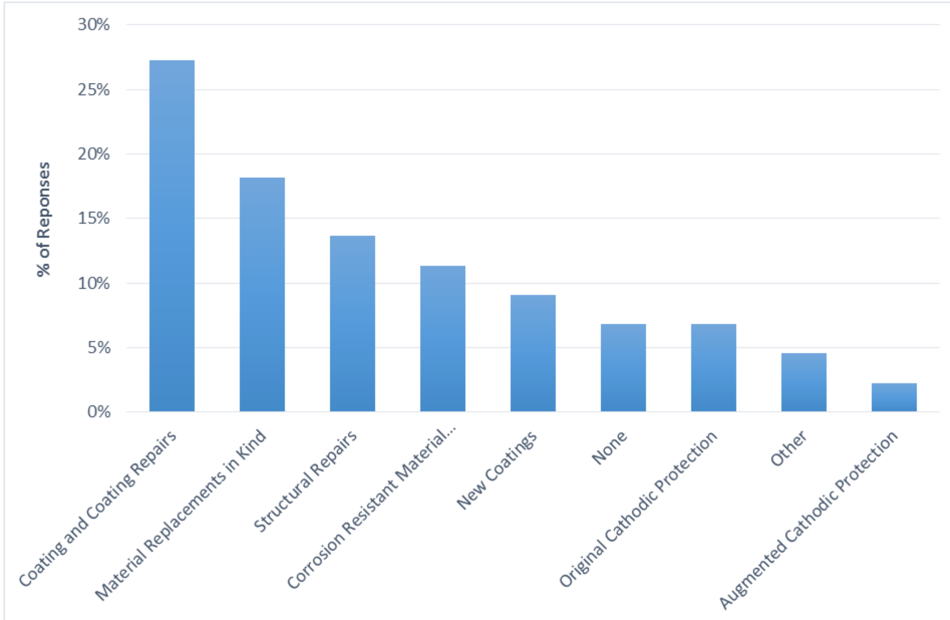

Figure B-25
Effective Mitigation Strategies, Large Metallic Components and Structures

Survey results indicate coating repairs, in-kind material replacements, and structural repairs as the most frequently implemented mitigation strategies. In addition to being the most frequently implemented mitigation strategies, these are also viewed as effective.

B.6.4 Related Discussions

The BOP contains a wide range of large metallic structures, such as traveling screens, water boxes, etc. These components are often constructed of materials susceptible to corrosion under normal service conditions. As a result, it is important to implement appropriate mitigation strategies to ensure plant reliability is maintained. Survey results indicate the majority of survey participants use visual examinations and conventional UT measurements to monitor the condition of large metallic structures.

As with heat exchangers, although two of the most commonly used inspection techniques for large metallic structures have detection limitations, survey results indicate relatively diverse degradation mechanisms have been identified. Additionally, plant interviews indicated few concerns for degradation of large metallic structures due to corrosion. The primary damage mechanism identified during interviews was coating delamination resulting from damage during installation or repairs, errors in the application process, and/or mechanical damage. *Additional Research* in the long term maintenance of coatings may benefit the reliability of large metallic components and structures.

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