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Guidelines for Prioritizing Inspections of Aging Plant Infrastructure

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Guidelines for Prioritizing Inspections of Aging Plant Infrastructure

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Product Description

This report outlines an approach that utilities can employ when prioritizing the inspections and testing of infrastructure at fossil power plants. The equipment and systems considered in this report include cabling, piping, tanks, building structures, chimneys, railways, and related infrastructure. The report also provides information on assessment methods suitable for evaluating these infrastructure systems.

Background

Many fossil power plants today are operating beyond their original expected life spans, increasing the risk that degradation of major infrastructure elements will significantly affect plant viability. Although many of the major plant components for power generation have been the focus of condition assessment and improvement programs in recent years, many infrastructure components have not been targeted by such efforts. Infrastructure therefore presents an additional element to the prioritization, planning, and scheduling of plant maintenance and projects.

Objectives

Prioritization of resources depends on plant and utility goals and on the impact infrastructure systems can have on these goals. Decisions must be made regarding how much effort and expense should be allocated to evaluating these systems. Based on available information and experience, decisions will need to be made regarding questions such as what percentage of each system should be tested, what assessment methods should be utilized, and how these activities compare to other necessary work.

Approach

The Electric Power Research Institute (EPRI) was tasked with developing a standard set of guidelines to consider when prioritizing the condition assessment of plant infrastructure components. Researchers reviewed existing material and conducted discussions with industry personnel. This report defines the components considered as plant infrastructure and the applicable inspection and assessment activities pertinent to each area. The report presents a risk-based approach for prioritizing these inspections and assessments.

Results

The guidelines in this report have been developed to support effective utilization of available resources. Basic descriptions of applicable inspection and assessment activities for power plant infrastructure are provided. The report also documents a common process for prioritizing these types of activities in conjunction with other plant maintenance.

Applications, Value, and Use

The guidelines consider the complexity of projecting future condition and determining the risk relationship among the different infrastructure systems at a fossil power plant. In addition, assessment methodologies and inspection tests are provided to assist in evaluating the current condition of systems.

Keywords

Plant infrastructure
Aging
Condition assessment
Plant life extension
Risk analysis

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Section 1: Introduction

Background

Many fossil plants today are operating beyond their original expected life spans. Age-related degradation continues to cause equipment reliability issues that pose problems in power plants. It is necessary to address the new and continuing issues that aging plants are facing in order to extend their effective operating lives. Although many of the major components of the power plant have been the focus of condition assessment and improvement programs in recent years, most infrastructure systems and components have not. This increases the risk that degradation of major facility infrastructure elements will significantly impact plant viability.

These structures, systems, and components (SSCs) need to be assessed to determine their condition and viability to meet future operating modes. A significant factor in maintaining plant reliability for the remainder of the plant's life is the ability to efficiently manage the effects of aging. The goal of this guideline is to maximize plant availability and reliability by focusing attention and resources on infrastructure systems. This report presents guidelines that utilities should consider when prioritizing the condition assessment of these infrastructure elements.

Plant Infrastructure Elements

For the purposes of this report, plant infrastructure is considered to be composed of SSCs that are not directly related to power production. The assets to be considered in this report include the following systems and structures:

- Cabling
    - Low-voltage
    - Medium-voltage
    - Instrumentation and control
- Piping systems
    - Above-ground
    - Buried
- Tanks
    - Above-ground
    - Buried

- Chimneys and stacks
- Ash ponds and dams
- Building structures
    - Reinforced concrete
    - Structural steel
    - Wood and timber
- Cooling towers
- Intake structures
- Railways

Approach

The report outlines a risk-informed approach for selecting the optimal condition assessment activities for SSCs at a fossil power plant. This is a two-part process. First, inspection and assessment activities that allow determination of the condition of each SSC must be identified. Second, these activities must be assigned values of risk based upon probabilities and consequences. The use of a risk-informed prioritization process can identify the most effective scheduling of assessment activities. This ensures that available resources can be used to most effectively enhance plant safety, availability, and reliability. This methodology for prioritizing inspection and assessment activities involves factors such as the following:

- Expected operating modes
- Regulatory requirements
- Environmental constraints
- Safety
- Cost
- Resources
- Equipment history
- Available technology

In any risk-informed analysis, there are three key aspects that come into play: risk identification, risk assessment, and risk mitigation [1]. These three aspects constitute the basis for risk management fundamentals and are associated with each of the various phases of risk management. A risk-informed analysis is an approach that pays off by doing the following:

- Providing a foundation for what deciding actions to take (in terms of monitoring, maintenance, and replacement), when to take them, and why they should be taken
- Helping to identify known causes of failure, instigators of failure, and degradation patterns and timing

- Supporting long-term plant availability, safety, cost control, and capital planning
- Providing a standardized process that can be used across systems, units, plants, and fleets

Determining the risk importance of an SSC requires the determination of the probability of failure of each SSC, as well as the consequences of the failure.

The following are the major actions involved in the process:

- Identifying the systems and equipment to be evaluated
- Identifying risk-significant components based on experience, engineering judgment, and historical data (from the unit, plant, utility, industry, and similar industries)
- Determining a preliminary ranking of the systems and key components based on history and the judgment of knowledgeable individuals
- Understanding the degradation mechanisms for each system or component to determine the impact of aging mechanisms and in-service wear
- Determining the appropriate assessment methods
- Determining the appropriate level of assessment based on experience, potential consequences, and cost
- Determining the appropriate locations to be inspected within the identified systems
- Determining the potential consequences for each system

Once the above analysis and information gathering has occurred, the information from the inspection and assessment activities can be taken and used to support a probability and risk analysis process. Section 2 discusses such a process. The outcome of this process will provide information that will allow relative comparisons between equipment in terms of impact to reliability, safety, and cost. It can help integrate disparate results from tests on many different systems and provide a more common basis for selection of activities. These outcomes can be used as input to each plant's work management process, allowing projects to get "on the radar" and into planning and scheduling processes with an accurate prioritization. This will support a more optimum prioritization of assessments and resource utilization.

Section 2: Risk-Informed Decision Making

Background on Risk, Probabilities, and Consequences

An important aspect of business management is the ability to project and forecast metrics in terms of expected values. In the power generation industry, the risks associated with safety, availability, and reliability are metrics that can all be addressed using the concept of *expected value*. This approach can be used to predict the probability of an SSC failure and assess its impact on plant performance and safety. This concept of expected value is widely used in business processes that involve future projections with substantial uncertainty. Expected values are based on two factors [2]:

- A sample space that includes a set of values with defined units (time, cost, equipment condition, plant performance, and so on)
- A likelihood associated with each of the values within the sample space

As an example, utilities project annual load demand as an expected value (or range of values) representing the most likely load demand for a future year. To determine these expected values in a sample space, probabilities and probability distributions are developed. These distributions address the likelihood that specific expected values within the sample will actually occur. The expected value in a sample is the value that exhibits the highest probability of occurrence. Figure 2-1 presents an example of a probability distribution for a population. Data on the far left and far right of the population distribution exhibit low probabilities of occurrence. The highest probabilities are located in the center of the sample space.

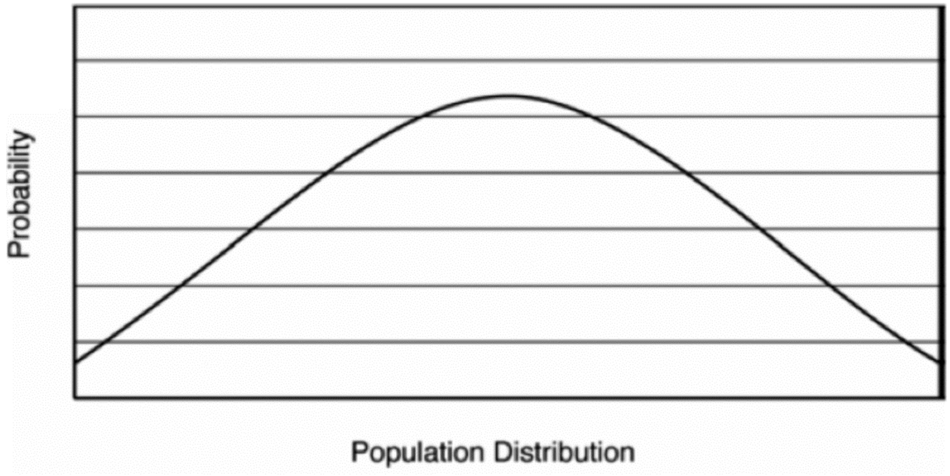

Figure 2-1
Normal probability density function

This concept of expected values and probabilities is an integral part of risk management. *Risk management* is a forecasting-oriented practice that can be used to project and manage expected outcomes and support management decisions. *Risk* is a commonly used term that quantifies the effect of any number of potential outcomes. Risk is quantified by first assigning a consequence value (in terms of dollars, lost generation, or some other measurable unit) and then assigning a probability of achieving that outcome. Risk is simply the product of these two factors.

Risk = Probability x Consequence

In the power generation industry, consequence is primarily driven by equipment failures. These failures can stem from a number of causes, including age-related degradation. Risk-informed approaches can be used to get the maximum value from scarce resources and establish an important link between decision making and performance goals.

The Risk Grid Concept

Because risk is a function of both the probability of an event occurring and the measurable consequence of the event, variations in either can result in greater or lesser amounts of risk. For example, a low probability of an event coupled with a low consequence of that particular event equates to a low level of risk. Similarly, a high event probability coupled with a high consequence translates into a high level of risk. These concepts are straightforward and fairly intuitive; however, a concept that is often overlooked arises when one of these components of risk dominates the risk level. A classic question involves comparing one outcome that has a high probability of occurrence and a low consequence against another outcome that is characterized by a low probability and high consequence. Which potential outcome has a greater significance? This question can begin to be addressed through the use of a risk grid as shown in Figure 2-2.

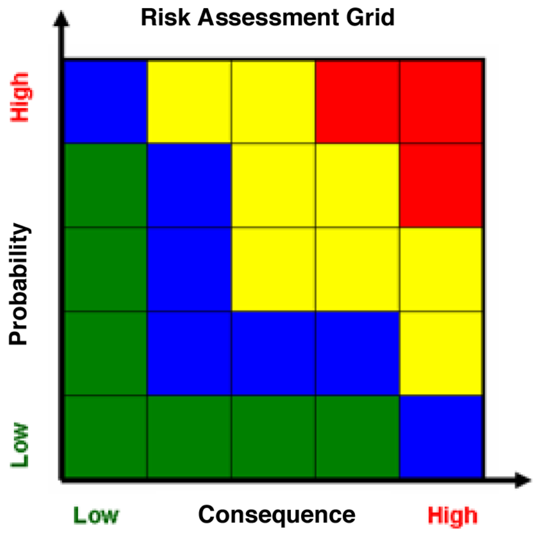

Figure 2-2
Risk grid

As illustrated in Figure 2-2, events can carry varying levels of risk. This is designated by the shading on the grid. Events in the red regions carry more risk than those in the green regions. It then follows that events with low probability and high consequences can carry as much (or more) risk significance as events with high probabilities and lower consequences, and vice versa. This approach to a risk assessment allows one to evaluate the level of risk at any given instance and assign a quantifiable value to that outcome [2,3]. By forcing one to consider probability and consequence separately, a risk grid reduces subjectivity in prioritizing maintenance activities. The risk grid can be a valuable first step in a hierarchy of future risk-informed methods that are more rigorous and quantitative.

The Evolution of Risk Analysis to Include Time-Based Methodologies

The concept of a risk grid provides a framework for quantifying risk levels defined by combinations of both probability and consequence. This approach is typically employed using the current state of risk and applies a constant risk level corresponding to a single point in time. However, one of the benefits of conducting risk analyses is the ability to project levels of future risk in terms of expected values. In relation to the risk grid described previously, future risk can be considered by adding a time dimension to both the probability and consequence axes. Both components of risk then become functions of time, and the new risk equation takes on the following form:

$$\text{Risk}(t) = \text{Probability}(t) \times \text{Consequence}(t)$$

In graphical form, the risk grid evolves into a three-dimensional cube in which the probability and consequence can change depending upon their expected future projections. This results in a "dynamic" evaluation of past, present, and expected values of risk. Using only the current values of probability and consequence, as shown in Figure 2-2, could be referred to as a "static" evaluation of risk. The time-based risk matrix takes on the form presented in Figure 2-3.

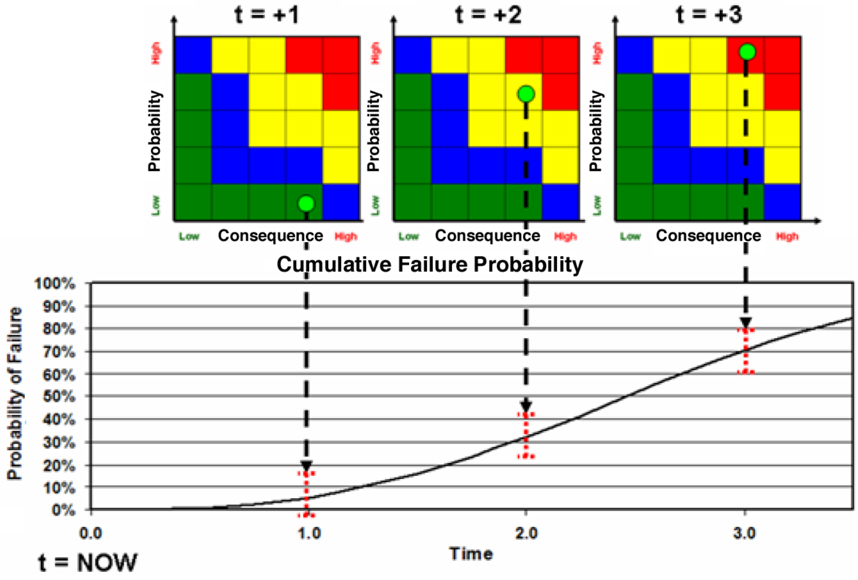

Figure 2-3
Dynamic application of a risk grid to time-based risk

The example in Figure 2-3 illustrates a situation in which the cumulative probability of an event is projected to continually increase with time while the consequence remains constant. At one point of time in the future, t=1, the probability is expected to be relatively low. As the projections are made relative to future times t=2 and t=3, the probability is expected to significantly increase. Corresponding to this expected increase in probability, the risk level is expected to continually increase over time as well. This is represented by the fairly low levels of risk at t=1 up to significant levels of risk at t=3. Although this example characterizes a dynamic probability function and a static consequence function, the concept of a dynamic consequence function is a possibility and would have similar effects on time-based risk levels. This could be attributed to the changes over time in replacement power costs associated with forced outages, or to other examples of factors that cause the consequences of equipment failures to increase or decrease.

This approach provides the foundation for determining expected values of risk. The key to this approach is the ability to quantify both the expected probability and expected consequence values. Numerous technical and statistical practices can support the modeling of equipment failure probabilities. These include Weibull analysis of historical data on component life; failure modes, effects, and criticality analyses (FMECA); and component probabilistic remaining life calculations. A detailed discussion of these approaches is beyond the scope of this report. In the context of this report, it is important to understand the concept of how the results of these techniques can be applied and what potential opportunities they provide.

Identifying Critical Equipment

In developing a risk-informed approach to maintenance decision making, it is necessary to develop a relationship between equipment, systems, and maintenance strategies. This provides the foundation to assess risk levels, identify sources of risk, and link risk-mitigating maintenance practices to these sources of risk. In a risk-informed approach, it is important to first understand the sources of equipment risk within the overall hierarchy of components, systems, plants, and generating fleet. A typical equipment hierarchy is shown on the left side of Figure 2-4. The levels in this diagram also represent different groups of risk. At the top of the hierarchy are the major business levels including company, department, region, and plant. Below that are levels within the plant, which are unit, system, and equipment. Each piece of equipment has one or more significant failure modes, and each failure mode has associated risk. Risk aggregates vertically through the hierarchy, meaning that the individual risks of all failure modes for a piece of equipment add up to the risk for that equipment, the risks for all equipment in a system add up to the risk for that system, and so on [2].

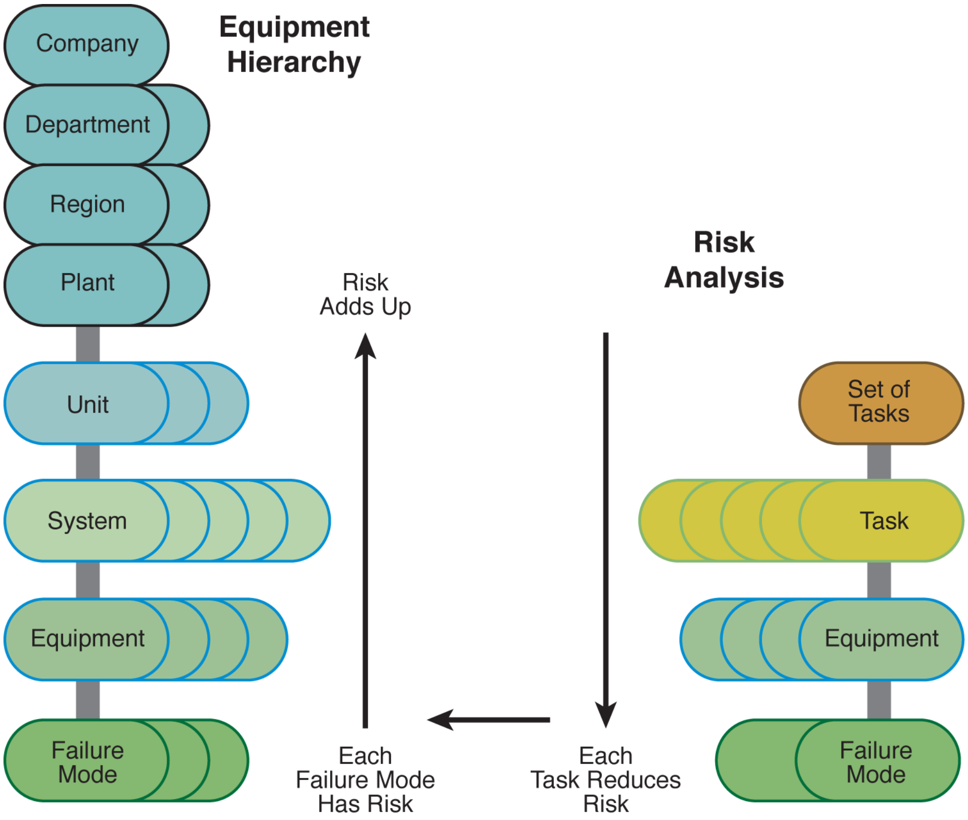

Figure 2-4
Equipment hierarchy in the context of a risk-informed approach

The right side of the diagram in Figure 2-4 shows how maintenance tasks relate to the equipment hierarchy in a risk analysis. Maintenance tasks are performed on plant equipment. These maintenance tasks are intended to address specific failure modes and reduce the probability of occurrence. Successful reduction in the probability of a failure mode occurrence results in a reduction in equipment risk.

The first step in a risk analysis is to define a detailed equipment hierarchy. This can often be leveraged from previous maintenance optimization efforts such as implementation of a computerized maintenance management system (CMMS). The determining factor for developing these hierarchies is that the equipment analyzed should have significant risk or significant consequence. This risk significance can be determined through screening techniques that identify areas of high potential benefit. The criteria for establishing risk significance can vary from organization to organization—or even from application to application—and can be adapted to fit any metric or value that is appropriate.

Information Required to Support Risk-Informed Methods

A hierarchal approach to risk-informed maintenance management provides the structure to identify sources of risk, assess risk, and relate risk-mitigating maintenance practices to these sources of risk. It is important first to have an understanding of equipment failure mechanisms and modes, to monitor equipment condition, and to project expected equipment health using failure probability. In addition, information on equipment failure consequences, maintenance task effectiveness, and maintenance costs is needed. These various process inputs all have important functions and necessary requirements. The following subsections address three of the most important inputs—failure probability, consequence, and risk mitigation—and discuss the necessary requirements for each [2].

Failure Probability Data

The most influential inputs used in an equipment risk analysis are the data that define equipment failure probability over time. These failure probability profiles must reflect the current condition of the equipment and, more important, the expected likelihood of failure of the equipment in the future. The approach to developing failure probability profiles is similar in nature to that used in established reliability-centered maintenance (RCM) practices. The process starts with an understanding of failure modes and their associated degradation mechanisms and effects. Based on this understanding, a projection of equipment condition can be established, leading to a time-based failure probability distribution for each mechanism that identifies the expected failure time frames. Figure 2-5 illustrates how a system can be broken down into failure modes and associated failure probability projections.

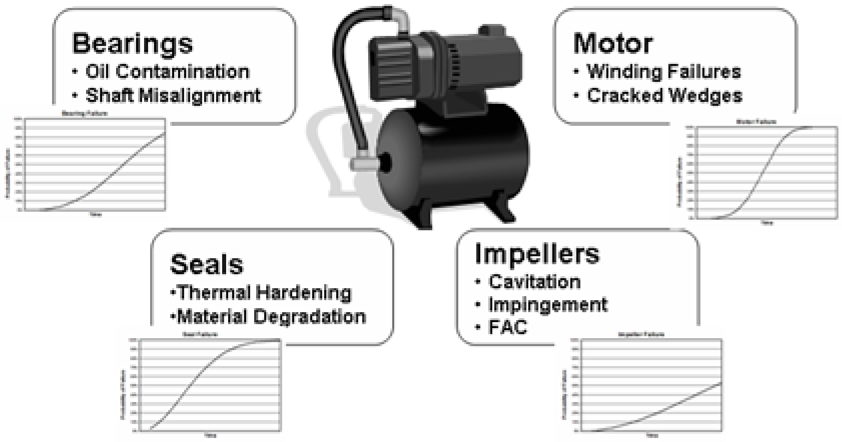

Figure 2-5
Failure data requirements for equipment hierarchy

This approach to estimating probability of equipment failure can become rigorous and complex. A significant amount of information is required to develop such projections. Sources such as industry data, equipment handbooks, and guidelines on equipment reliability can supply useful information concerning failure mechanisms and time frames, as can vendor recommendations and analyses. Industry failure databases (for example, the Generating Availability Data System maintained by the North American Electric Reliability Corporation) also provide failure data for hundreds of equipment types [2,3]. Analyzing individual plant failure histories and documenting the knowledge of craft labor can customize information to particular pieces of equipment. In general, the three basic sources of data used to support failure probabilities are 1) expert elicitation, 2) historical equipment reliability data, and 3) focused engineering calculations on component remaining life.

Consequence Data

The second parameter used in a risk analysis is failure consequence. Consequence data describes all aspects of the effect of a component failure (lost availability, repair, damage to nearby equipment, safety, and so on). Consequence can be assessed by analyzing cause and effect relationships that can be as detailed as the analyst feels are appropriate. Typically, when formulating consequence information, a variety of sources of information are available. Defining consequence is integral not only to the results of a risk analysis, but also to how the results can be applied and used.

One of the most important characteristics of consequence is the unit of measure that is established to represent risk. For example, one organization may choose to interpret consequence (and risk) in terms of monetary value. Conversely, another may choose to establish risk in terms of lost production opportunity. The important concept is that this risk unit is determined by the selection of how a consequence is characterized. This unit of measure will serve as a common unit to which all other measures of business can be converted and compared. The selection of consequence units should be carefully considered at the outset of an analysis because this choice will determine the business metric that is being optimized.

Risk Mitigation Information

After evaluating failure probabilities and associated consequences, the final key input needed in a risk management analysis is to define the effect of actions taken to mitigate risk. Defining these actions could involve identifying practices or steps that have the ability to reduce levels of risk by either reducing the probability of identified events or reducing the consequence of an event. In the field of physical asset management, this concept primarily pertains to the operations and maintenance of equipment. Most risk mitigating tasks involve preventive maintenance (PM) or condition-based maintenance (CBM) practices. These practices are designed to reduce the probability of equipment failure. Quantifying the effectiveness of these practices becomes an extremely important aspect of the analysis. This provides the basis for evaluating the benefits of various risk mitigation practices. Of equal importance is determining the cost of each action in terms of personnel requirements, cost of materials, lost production, and so on. These costs are used to evaluate the trade-off between the benefit in terms of risk mitigation and the associated cost.

Figure 2-6 depicts the concept of risk mitigation. Maintenance can provide benefits resulting from reduced failure probabilities, but it also involves a cost.

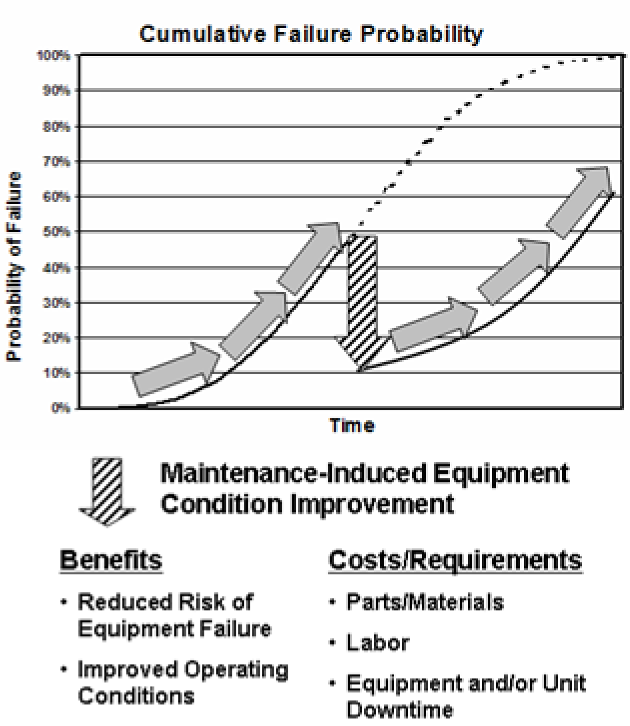

Figure 2-6
Benefit-to-cost trade-off of risk-mitigating maintenance

Another important element of risk mitigation practices involves the condition assessment practices. Condition assessment includes use of both online monitoring systems and direct observation. These assessments provide information and data concerning both the current condition of the equipment and the expected condition of the equipment in the future. Consequently, uncertainty associated with some failure probability projections can be reduced by replacing those projections with projections that are based on direct observation of the operating equipment. Many times, this increase in condition knowledge can be of equal or greater value to an organization than conducting any physical maintenance on the equipment.

Application of the Risk-Based Approach to Plant Systems

The following steps should be performed to implement this risk-based approach to condition assessment of plant systems and equipment:

1. Look at all the applicable plant infrastructure systems and determine the critical components of each to be evaluated.
2. Collect data on failure modes and effects associated with degradation mechanisms and effects.
3. Develop a preliminary ranking of the systems and equipment.
4. Identify an expected failure probability based on historical information and judgment of knowledgeable individuals.
5. Determine the "unit of measure" for consequences such that it will provide a common basis for comparisons.
6. For each SSC, determine the appropriate level of analysis to match the expected risk versus consequence.
7. Analyze cause and effect relationships to determine probable consequences in terms of the chosen unit of measure.
8. Develop a risk grid to depict the results of analysis and relatively rank the critical infrastructure elements.
9. Utilize the results of the analysis as a basis to provide an initial indication of the order in which SSCs should be assessed.
10. For each assessment determine the appropriate assessment methods based on the criticality of the equipment and the expected consequences.
11. For each assessment determine the appropriate inspection/assessment locations and assessment methodology.
12. Based on the initial rankings and any constraints (such as need for equipment isolation, need for an outage, or scheduling of third-party support) schedule assessment activities in conjunction with other maintenance requirements utilizing the plant's work prioritization process.
13. Complete assessments and record results.

Section 3: Cabling

Overview

A power plant's cable system is not limited to field cables only, but also includes terminations, connections, and support and protective systems (such as tie-downs, trays, conduits, and ducts). Each element affects the operability of the cable system and must be considered in addressing the assessment of cabling systems. With many plants approaching or surpassing operating lives of 40 years, the aging of cables is becoming a concern.

The cable system for a fossil power plant is extensive and contains cables with different configurations and insulation systems. This requires each plant to know the types and configurations of its cabling to be able to complete a condition assessment. Cable life and the extent to which aging impacts this life is generally a function of the following:

- Proper conductor sizing
- Proper installation (with no installation damage such as adverse bends or crimping)
- Materials of construction (for example, conductors, jackets, and insulation)
- Operating environment (that is, presence of moisture, chemicals, harsh temperatures, dust, vibration, and so on)

Cables and terminations are generally accepted as components with extensive life expectancies. Most cables in a plant are expected to suffer few severe effects from aging. There are some materials that are more sensitive to aging than others and some locations in a plant that present a more severe environment. A review of the types of cables in use, in conjunction with the environments of the locations containing cables, allows a good initial determination between cables that will have a long life and those that could degrade significantly during plant operation [4].

Initial efforts are needed to identify the applicable cabling systems to be inspected, the environments they are operating in, and the criticality of each system. Cables are located in a wide variety of environments. This includes areas that provide a severe environment, as well as areas that will have no impact on material degradation. Cables located in the hottest, most adverse conditions should be given priority for early inspection. High temperature is the most common cause of deterioration of cable insulations and jackets in a plant.

Identification of potentially adverse areas for cables (in terms of heat, dust, vibration, chemical attack, high moisture, or chloride-rich conditions) and a limited inspection of cables in those areas will provide an indication of where emphasis should be put. If a number of significantly deteriorated cables are found, increased inspections may be warranted.

For plants that do not know the specific cables in use, scoping can be performed using procurement records, the experience of plant maintenance personnel, and walk-downs.

To aid in effectively inspecting cables and assessing their condition and reliability, plant personnel need to have an understanding of the leading indicators of aging degradation.

Cabling Inspections

Low-Voltage Cables

The following are the condition monitoring tests for low-voltage cables [5]. Inspection is generally restricted to tests that evaluate the chemical and physical properties of the polymers:

- Use of an indenter polymer aging monitor, a nondestructive test device that measures the compressive modulus of the cable jackets
- Various chemical tests, including swell and gel factor (cross-linked polyethylene [XLPE] and polyvinyl chloride [PVC])
- Oxidation induction time and oxidation induction temperature (XLPE)
- Nuclear magnetic resonance inferometry
- Density (XLPE and ethylene propylene rubber [EPR])
- Visual inspection, where exposure allows, for the following:
    - Cracks in jackets or exposed insulation
    - Cuts in jackets or insulation
    - Cable discoloration, burn marks, or other visual indications of stress
    - Cable jacket and insulation hardness that is not as expected
    - Existence of liquids leaching from the surface or oozing from the conductor
    - Liquids or steam that are impinging upon cable from external sources

The indenter can be used in the plant, whereas the other methods require removal of a small sample of jacket or insulation for testing in a laboratory.

Electrical testing is generally not considered useful in evaluating the aging of cable polymers. The changes in electrical properties are nearly undetectable from even the most severe thermal aging. To complicate matters, most low-voltage cables are unshielded, making electrical testing more difficult due to the lack of ground plane around the insulation system under test. High-voltage testing methods are undesirable for condition monitoring of unshielded cable and may damage sound cable. Therefore, condition assessment tests for low-voltage cable are restricted to tests that evaluate the chemical and physical properties of the polymers. While most modern insulations for low-voltage cables are not affected by moisture, the metals of the termination systems and the conductors of the cables might deteriorate at the termination.

Medium-Voltage Cables

Factors that influence degradation for medium-voltage cables include insulation, type, condition of insulation shield, and cable rating. Various tests have been used to gain an understanding of the state of aged cable systems. These tests fall into three general categories in addition to visual inspection [6]:

- Withstand testing—designed to remove the weak link at the time of testing by causing it to fail at a convenient time for replacement. High-voltage tests can be destructive, shortening the life of aging cables. Experience has shown that applying direct current to extruded polymer cables frequently misses significant degradation and sometimes causes premature failure. This testing is recommended for paper-insulated, lead-covered cable. Examples include the following:
    - DC withstand tests (hi-pot)
    - AC withstand tests
    - Very low frequency (VLF) testing
- Diagnostic testing—provides an indication of current condition, allowing inferences to be made about future performance of cable systems. These tests are meant to be nondestructive, causing failure only if the cable has deteriorated to the point that failure in-service is already imminent. These tests differentiate between good, defective, and highly deteriorated cable insulation. Examples include the following:
    - Dissipation factor testing
    - Potential discharge testing
    - Dielectric spectroscopy
- Indenter modulus testing—performed using a nondestructive test device that measures the compressive modulus of the cable jackets.
- Visual inspection—performed where exposure allows. The principles are the same as for low-voltage cables.

Medium-voltage cables will have electrical deterioration mechanisms; therefore, a complete assessment of their condition cannot be performed using visual or tactile inspection alone. Cables that operate at or very near their limit rating for amperes should be identified and assessed [6].

Cables with long vertical runs must be properly supported. The weight of the cable can cause compression at the support point or excessive tension on the cable segment at the top of the run. Such physical stresses can adversely affect insulation life and cause early failure. It is essential to identify areas where medium-voltage cable has vertical runs of 25 feet (7.6 meters) or more and evaluate physical supports.

Instrumentation and Control Cables

Instrumentation and control cables that are properly installed, supported, and kept cool and dry should have a very long life. Longevity can be compromised by any of the following:

- Localized high-temperature environments under normal operating conditions
- High-resistance connections at terminations or splices
- Long-term wetting with respect to certain insulation types and applications
- Exposure to chemicals, oils, or hydraulic fluids
- Rodent damage to jackets and insulations

Electrical assessment with commonly available techniques will generally be of little use in detecting the onset of aging and may not detect deterioration even if the insulation is cracked in dry environments. Cables subjected to wet conditions should be tested via insulation resistance to ground or conductor to conductor, to determine if degradation has occurred. The following tests can be used to determine the condition of instrumentation and control cables [7]:

- Visual/tactile inspection
  - Discoloration
  - Cracking of the jacket
  - Loss of flexibility
  - Proximity to elevated temperatures
  - Rodent damage
- Indenter modulus testing
- Near-infrared spectroscopy
- Acoustic velocity assessment (ultrasonic velocity assessment)

Tray Systems, Conduits, and Junction Boxes

The following are general inspection criteria for tray systems, conduits, and junction boxes to ensure that acceptable conditions exist for cables and support components [5]:

- Tray Systems
  - Support brackets are sound and anchored.
  - Covers (where provided) are in place and properly clamped.
  - No physical damage to trays exists.
  - No extraneous material (for example tools and trash) is in trays.
  - Cables lie properly in the tray and do not cross over edges or lie perpendicular to axis of tray across edges.
  - Cable drop-outs from trays are padded or otherwise protect cable from sharp edges of trays or conduits.
- Conduits
  - Conduits are properly anchored.
  - Connections between sections of conduit are not separated.
  - Cable entry to conduit is padded to protect cable (bell or other padding provided).
  - Flexible conduits are coupled to mating junction boxes and conduits.
  - Flexible conduit coverings and the conduit itself are undamaged.
- Vertical conduits and trays
  - Vertical runs of cables are provided with supports appropriate to the length and weight of the cable.
  - Cable is not pinched at the top of the run from weight of unsupported cable.
  - Cable supports are in satisfactory condition and have not failed.
- Junction boxes
  - Covers are in place and secured.
  - For boxes in wet areas, when terminal blocks are used, drip loops exist on wires coming from higher than the termination and conduits do not drain onto terminal strips.

The Risk-Informed Process Applied to Cabling

The following steps can be performed to evaluate a cabling system for prioritizing assessment activities utilizing the guidelines as outlined in this report.

1. At the outset, all applicable cabling systems should be reviewed by knowledgeable personnel to perform a preliminary ranking of these systems based on their criticality and expected impact on safety and plant performance. From this preliminary ranking, the systems deemed to have the greatest potential impact on safety and plant performance should be given the highest priority.

2. Review the systems/components of the highest-priority systems for their design basis, materials of construction, and the service environments that exist.
   - Do environmental stressors such as the presence of water, elevated temperatures, or proximity to harsh/corrosive chemicals exist?
   - Will materials impact condition? (Earlier-generation cabling such as products manufactured before 1975 having XLPE, butyl, or black EPR insulation should be given higher priority.)
   - What operational concerns exist? For example, does the cabling power key equipment or connect transformers to busses?
   - Are there weighting factors that will affect prioritization of the systems? For example, is the cabling normally energized, energized and loaded, or periodically energized?
   - Did construction methods create potential problems from pinching, tight bends, or the type of terminations utilized?
3. Review plant and industry history on cable failures for similar voltages, designs, construction methods, and environmental conditions. Determine the probable degradation mechanisms that will be experienced (for example, deteriorated insulation or stressed terminations) and expected mean times between failures.
4. Using the above information, determine the cause and effect relationship between degradation mechanisms and the operating environment of the cabling systems to determine a probable current condition and expected likelihood of failure. System walkdowns can aid in this evaluation.
5. After determining the expected likelihood of failure of a system or a key component, determine the consequences of component failure. There can be more than one consequence of the failure of a component (for example, lost availability, compromised safety, or repair/replacement costs). In comparing the consequences of one cable failure versus another cable failure (or cable failures versus failures on other key systems) the plant will need to have determined a unit of measure, such as lost generation.
6. Using the results of the probability and consequence analysis, create a risk grid to define the relationship between the probability of failure and the consequence of component failure. The results as depicted on the risk grid will provide guidance in prioritizing condition assessments of the systems based on expected impact to plant performance. Table 3-1 presents some sample risk relationships for cabling systems, and Figure 3-1 presents a sample risk grid based on those relationships.

Table 3-1
Sample risk relationships for cabling

System	Probability of Failure	Consequence (% Load Loss)
Low-voltage cable	Moderate	25% rated load
Medium-voltage cable	High	70% rated load
Instrumentation and control cable	Low	50% rated load

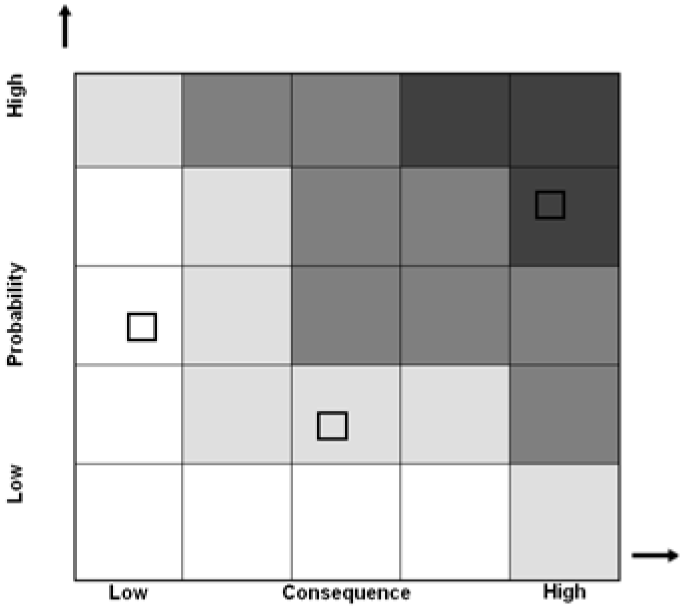

Figure 3-1
Sample risk grid for cabling

7. Select the assessment methodology, determine the number of inspection points, and select the inspection points. Considerations should include the following:
   - Level of perceived risk—low/high impact to the selected unit of measure.
   - Cost of inspection/assessment—visual inspection versus hi-pot testing or dielectric spectroscopy.
   - Extent and applicability. Do all components in a system require inspection? Is only a portion of the system in a high-risk area such as an exposed location with a harsh environment? Will an assessment of the cabling in this area provide a reasonable assessment for the system?
   - Availability of resources and existence of time constraints.
8. After assessment activities have been performed, update the existing risk grids to reflect current data on existing condition, expected likelihood of failure, and consequences of failure.

Section 4: Piping

Overview

Piping systems are designed and constructed in accordance with codes and standards that provide a margin of safety principally with respect to pressure integrity and release of product due to leakage. Pipeline integrity assessment refers to examinations carried out to determine whether a pipeline or piping system has adequate strength to prevent leaks or ruptures under normal operation and upset conditions. These examinations help to determine whether a particular system has been subject to internal or external corrosion. Whenever possible it is desirable to perform these assessments without disruption or impairment of serviceability.

Piping generally fails due to multiple root causes: mechanical damage, breakage, chemically initiated corrosion, or a combination of these. Integrity assessment is generally based on visual methods (direct observation, video crawlers, borescopes) or volumetric methods (ultrasonics, guided wave) to determine the amount of degradation (cracks, dents, thinning) of materials and the resultant effect on the piping system's integrity. Effective methodologies to determine the condition of piping systems depend on factors such as accessibility (above-ground, below-ground, elevated) and the materials of construction (steel, concrete, polymers).

Piping systems can be above-ground or buried. Whichever is the case, for the piping to be assessed the available test methodologies are the same. Assessment of above-ground systems will be simpler primarily because of their availability for direct visual assessment of external corrosion and leakage and greater access for wall thickness and integrity evaluations. Buried piping systems, unlike above-ground piping systems, corrode and foul from the fluid side and corrode or experience mechanical damage from the soil side. Measurement of soil characteristics can be used to rank their corrosivity and therefore the likelihood of corrosion of the buried pipe.

This continuing degradation is difficult to assess because the pipes are difficult to reach for inspection and because when buried pipes leak it can be very difficult to locate, assess, and repair the source of the leakage in a timely manner.

For buried pipe, cathodic protection systems are an important part of corrosion control, working together with existing coating systems. Since no coating systems are perfect, cathodic protection is necessary. The first check for cathodically protected pipe is to verify the adequacy of the cathodic protection system design and its maintenance. Cathodic protection needs to be monitored, maintained, and replaced at the end its of life to ensure that it is operating efficiently.

Piping Inspections

A range of assessment technologies are available to determine the condition of piping systems, as described in the paragraphs that follow [8,9,10,11].

Visual Inspection

Visual inspection technologies are suitable for detecting piping areas with deposits, recognizing severe corrosion damage, and locating leaks. In addition, video inspection may help identify the prevalent corrosion mechanisms by examining the prevailing metal loss patterns. Video inspection tools are available to examine either flooded or drained piping systems.

Tools for visual inspection include fiberscopes, borescopes, crawlers, and submersibles.

Fiberscopes

A fiberscope, also known as a flexible borescope, consists of a small-diameter (0.07–1 inch [1.8–25.4 mm]) fiber optic bundle up to 20 feet (6 m) long. These units are suitable for examining small-diameter piping and difficult-to-reach areas. These tools provide the inspector with a light source, a means of focusing the image, and a manipulator that enables the camera tip to be rotated up to 120 degrees in any direction. Large-diameter piping is more difficult to inspect with fiberscopes because of the tool's inability to climb and reach the upper surface areas.

Borescopes

Borescopes can be used to detect severe corrosion damage in large-diameter piping. These units are rigid and larger in diameter than fiberscopes, and include rotating prisms and lenses that enable the inspector to have a panoramic view (-7 to 133 degrees) as well as zoom in and examine areas of interest including cracks and weld roots. Submersible borescopes have a 10-foot (3-m) inspection range. Units that are not watertight can reach up to 45 feet (14 m).

Video Crawlers

Crawlers permit the expansion of the video inspection range up to 300 feet (91 m), and some are submersible up to a depth of 100 feet (30 m). Their long range reduces the number of access ports required, as compared to those needed for fiberscopic or boroscopic examination. The ports, however, must be larger in size and may require the dismantling of valves. The crawler systems are designed modularly so that the user can install the appropriate camera for the job. Some can even be fitted to perform ultrasonic thickness measurements. Crawlers are cumbersome climbers. However, some units are designed to climb by deploying magnetic wheels or spring-loaded 360-degree wheel configurations. In complex piping configurations, maneuvering the tether cable around the bends limits the range of these vehicles.

Submersibles

Submersible vehicles get around the climbing difficulties of the crawlers while maintaining similar examination range (300 feet [91 m]) and water depth capabilities (100 feet [30 m]). Submersibles are less flexible with regard to the type of cameras they can carry. Since these vehicles and their tether cables are designed to be neutrally buoyant, the manufacturers typically offer packaged units rather than the modular systems available for crawlers. As with crawlers, maneuvering the cable around bends may limit the vehicle's range. Finally, submersibles require that the piping system be flooded during the examination.

Direct Observation

During visual examination, important details can be collected that may be useful for future analysis and for deciding on the type of nondestructive evaluation (NDE) to be used for further analysis. Visual inspection should be carried out as a complementary method to other NDE methods. In performing visual checks it is important to know the type of defect that can develop and to recognize the areas in which failures can occur.

Visual examination of plant system components by an experienced inspector can reveal the following information:

- General condition of the component
- Presence of a leak and other abnormal operation conditions
- Presence or absence of surface deposits (such as oxide films or corrosive product on the surface), scaling, corrosion, erosion, discoloration, and oxidation bulging
- Presence or absence of cracks, orientation of cracks, and position of cracks relative to the various zones in the case of welds
- Surface porosity, unfilled craters, contour of the weld beads, and probable orientation of the interface between the fused weld bead and the adjoining parent metal
- Potential sources of mechanical weakness, such as sharp notches or misalignment
- Missing parts, dimensional conformances, gross defects visible on the surface, and distortion during fabrication and in service

Optical aids (cameras, binoculars, and scopes) are beneficial and recommended to magnify any defects that cannot be detected by the unaided eye and to permit visual checks of areas that are not accessible. They should be used whenever appropriate.

Pressure Tests

Hydrostatic proof testing is well understood for new construction testing and can be useful in ensuring the integrity of corroded pipe. The purpose in hydrostatic testing a pipeline is either to eliminate any defects that might threaten its ability to sustain its maximum operating pressure or to show that no such defects exist. Hydrostatic testing consists of increasing the pressure above the operating pressure to see whether any defects with failure pressures above the operating pressure exist. If defects fail and are eliminated or if no failure occurs because no such defects exist, a safe margin of pressure above the operating pressure is demonstrated. Subsequent hydrostatic tests ensure that no significant time-dependent deterioration of a component has taken place and that any segment that has been significantly degraded will be revealed and eliminated.

Pressure tests are frequently used to demonstrate the strength of pipelines, generally immediately after construction. There are limitations associated with such testing when applied after the pipeline has been in service for a number of years:

- The method provides no information regarding the depth or location of subcritical flaws.
- Pressure testing requires the pipeline to be taken off line.
- It can be difficult or nearly impossible to remove fluids from the pipeline after a pressure test. Such residual fluids can potentially initiate internal corrosion and perhaps facilitate microbiologically influenced corrosion.

Leak Detection

Visual

The simplest and least effective method of leak detection is visual inspection of the ground surface for evidence of wetness. Discovery of leakage may be incidental, or it may occur during planned walkdowns of the pipe route.

The limitations of this method are the following:

- The ground surface over the pipe has to be visible, and therefore visual inspection does not apply to pipes under buildings, roads, or concrete surfaces, or to areas that are wet by nature.
- The ground surface has to be dry for the leak to be visible.
- A leak may flow down into the ground and into an aquifer and not appear at the ground surface, or may appear only later.

- The liquid release plume may reach the ground through a complex pathway and appear at a location remote from the origin of the pipe leak.
- Detection of liquid on the surface typically occurs too late, after the pipe has incurred large losses of liquid.
- The pipe may be too far underground for leakage to appear at the ground surface.

Dyes

Dyes are added to flowing water, and leaks are detected by inspection for dyed water at the ground surface. Dyes can be fluorescent and detectable with UV lamps. Dye can also pinpoint leaks under water. Whenever dyes are used it needs to be verified with the environmental department that they can be released into the environment, including bodies of water.

The advantages of this method include the following:

- A long pipeline can be tested at one time.
- The pipeline can be filled and remain in service during the test.
- The location of a leak along a pipeline is indicated by the dye color at the surface.

The disadvantages of this method include the following:

- The backfill must be permeable to permit the dye to reach the surface.
- Surface dye may not indicate the exact leak location because the leaked liquid might migrate a considerable distance through the soil.
- Small leaks are not readily detected.
- The dye may not be compatible with the pipe material.
- Environmental restrictions may preclude the use of dye.

Tracer Gas

A tracer gas leak test is used to pinpoint the source of a leak. Volatile tracer gases are introduced into the liquid-filled pipe. A portable probe, or a series of fixed probes, can be used to analyze the ground surface for signs of tracer vapors that would indicate a leak. Typical tracer gases that are added to liquids include helium and hydrogen.

The advantages of this method include the following:

- The use of tracer gas permits a long pipeline to be tested at one time, between isolation points.
- The pipeline can be filled and remain in service during the test.

- The location of a leak along a pipeline is clearly marked by the location of the tracer.
- Depending on the conditions, leak rates as low as 0.1 gallon (0.4 liter) per hour can reportedly be detected.

The disadvantages of the method include the following:

- The backfill must have some degree of air permeability to let the gas seep to the surface.
- If the pipe is under a concrete mat, probes may have to be installed in holes dug through the concrete.
- The leak source may be difficult to locate if the pipe is under a concrete mat.
- The tracer gas may not be compatible with the pipe material.
- The tracer gas may not be compatible with the system and its equipment.

Ground Penetrating Radar

Ground penetrating radar (GPR) can be used to detect leaks in buried pipe. This technique looks for voids that have been created in the soil due to saturation caused by water washing. Ground penetrating radar uses radar pulses to image the subsurface; more specifically, it uses electromagnetic radiation and detects the reflected signals from subsurface structures. It can detect objects, changes in soil material, and soil voids and cracks.

The limitations of this technology are the following:

- GPR can only detect down to a certain distance. The depth range is limited by the electrical conductivity of the ground, the transmitted center frequency, and the radiated power.
- The soil may not be susceptible to void formation.
- Considerable expertise is necessary to effectively design, conduct, and interpret GPR surveys.
- Interpretation of the data is generally non-intuitive to the novice.
- Liquids in soils can cause rapid signal attenuation.

Acoustic

When the flow of gas or liquid through a leak reaches a certain velocity, the flow will transition from laminar to turbulent. When this happens, the leak generates sound that propagates through the structure to where it can be detected by an acoustic emission sensor. For very large leaks, this sound can be directly audible, but for medium and small leaks the only way to detect this sound is with sensors targeted at higher frequencies (in the ultrasonic range) and as structure-borne sound. The sound produced by turbulent flow tends to produce continuous signals that are characterized by measuring the level of the voltage signal coming out of the sensor over some fixed period of time.

Testing of buried pipelines is done with two or more sensors attached to the outside of the pipe. The sensor response is examined for indications that a leak is nearby. Once it has been determined which sensors bracket the leak, the location of the leak can be determined. The test is conducted with pressure applied to the pipeline. Sometimes this can be done without removing product and without taking the pipeline out of service.

The limitations of this method include the following:

- The sensitivity is directly related to the leak rate. Under ideal conditions, leak rates as small as 0.1 gallons (0.4 liters) per hour can be detected, although minimum sensitivity is usually around 1.0 gallons (4 liters) per hour.
- Sensor spacing can become an issue when multiple leaks may exist between two sensors at different locations.
- Since structural sound attenuates as a function of distance, the distance between sensors is critical for this method. In addition, attenuation is more severe at higher frequencies than it is at lower frequencies. Therefore, most applications use a sensor that operates at the lowest frequency possible without interference from background noise.
- In order to install sensors, the pipeline must be excavated at various locations. Coatings must be removed so the sensor can be coupled to the bare metal. As an alternative, there are devices that can be forced into the ground until they contact the pipeline. These devices use a waveguide concept in order to bring the acoustic emission signal to the surface where a sensor can be installed.

Additionally, acoustic signals emitted from the leaking fluid can be detected from within the pipe. These inspections are conducted while the pipe is in service by inserting a sensor into any tap 2 inches (51 mm) or larger. A small parachute uses the flow of the water to draw a tethered sensor through the pipeline. It is reported that pinhole leaks as small as 0.005 gallons (19 ml) per minute can be located with an accuracy of approximately 18 inches (500 mm) along the pipe.

Wall Thickness/Corrosion Detection

Ultrasonic Testing

Ultrasonic testing (UT) is a volumetric NDE method well suited for examining piping in order to detect and characterize corrosion and cracks. Ultrasonic examination technology is commonly used in the power industry and many other industries. It is used to assess material conditions of newly manufactured materials as well as those that have been in service for years. It can be used on many materials, including metals, plastics, composites, fiberglass, ceramics, and glass. It can be used to accurately measure material wall thickness or identify imperfections. It is the most widely used NDE method for measuring wall thickness.

A significant advantage of ultrasonic testing is that access to only one surface is needed. Therefore, operating systems such as piping systems do not need to be taken out of service to obtain thickness measurements.

Advantages of ultrasonic testing include the following:

- It can provide accurate thickness measurements.
- Only single-sided access is needed when the pulse-echo technique is used.
- The depth of penetration for flaw detection or measurement is superior to that of other NDE methods.
- It is accurate in determining reflector position and estimating size and shapes.
- It provides essentially instantaneous results.
- Detailed images can be produced with automated systems.
- It can be made to be sensitive to detection of in-service discontinuities such as cracks.

Disadvantages of ultrasonic testing include the following:

- At least one surface must be accessible to transmit ultrasound into the material.
- Techniques can be complex and thus require highly skilled ultrasonic personnel and procedures.
- Surface finish must be adequate to promote transmission of ultrasonic energy into the material.
- It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.
- Materials that are rough, irregular in shape, quite small, exceptionally thin, or nonhomogeneous are difficult to inspect.
- Coarse-grained materials such as cast iron can be difficult to inspect due to low sound transmission and high signal attenuation.
- Linear defects oriented parallel to the sound beam can go undetected.
- Special techniques may be required to detect certain flaw types such as small isolated pits or near-surface flaws.

Magnetic Flux Testing

Magnetic flux leakage testing is a type of electromagnetic NDE methodology used to detect discontinuities in a material. Magnetic particle testing, which uses particles to show indications, is a variation on flux leakage techniques. Although it is primarily used to detect, locate, and characterize corrosion, it can also be used to detect mechanical damage and some surface-breaking cracks. In this process, the material is magnetized and sensors are used to detect interruptions in the magnetic field through the metal media. The sensors detect these changes in the flow of the magnetic field in three directions (axial, radial, and circumferential) to characterize the anomaly.

The advantages of magnetic flux testing include the following:

- When used with other methods it can provide a quick and relatively inexpensive assessment of the integrity of ferromagnetic materials.
- It is commonly used for inspecting piping systems utilizing in-line inspection tools known as pigs.
- There is no need for couplant between the sensor and the pipe wall.
- It can be used internally or externally.
- It can use permanent magnets or electromagnets (the former being more widely used because they do not require an electrical power supply).

The disadvantages of magnetic flux testing include the following:

- The detection sensitivity with regard to external corrosion (or the corrosion/erosion to the other side of the wall) is limited, especially in the case of larger wall thicknesses.
- The signal depends on the material properties as well as the wall thickness. For determining wall thickness a calibration process is required.
- It is only suitable for ferromagnetic materials.
- The accuracy of depth measurement is reduced because of the indirect nature of the method as compared to the direct measurements achieved by ultrasound.
- Signals are quite complex and require the use of mathematical models and the availability of an extensive database of responses for accurate depth sizing.

Eddy Current Testing

Modern eddy current methods offer unique, low-cost methods for high-speed, large-scale inspection of metallic materials such as those used in high-pressure, high-temperature systems. The eddy current method of inspection depends on the principles of electromagnetic induction for inducing eddy currents within the material placed adjacent to the induction coil. It is used to identify or differentiate among a wide variety of physical, structural, and metallurgical conditions in electrically conductive metals and metal parts. Eddy current inspection can be used to do the following:

- Measure or identify conditions and properties such as electrical conductivity, magnetic permeability, grain size, heat treatment condition, hardness, and physical dimensions
- Detect seams, laps, cracks, voids, and inclusions

- Sort dissimilar metals and detect differences in their composition, microstructure, and other properties
- Measure the thickness of a nonconductive coating or a nonmagnetic metal coating on a magnetic metal

Because eddy currents are created using an electromagnetic induction technique, the inspection method does not require direct electrical contact with the part being inspected.

The advantages of eddy current testing include the following:

- It is relatively fast (for tubing inspection with a high digital sample rate, test speeds of up to 260 inches [660 cm] per second can be achieved).
- It has good sensitivity to material property changes (physical/chemical) of the test object.
- It has good sensitivity to surface cracks.
- Portable, state-of-the-art equipment is available.
- Configuration is easy, and automated examination is possible.
- It enables easy storage of data for past and future review and comparison (which is useful for data trending).
- It utilizes multi-frequency, multi-channel data acquisition processes for efficient monitoring of eddy current signals.

The disadvantages of eddy current testing include the following:

- Only conductive materials can be tested.
- The surface must be accessible to the probe.
- The required skills and training are more extensive than for other techniques.
- Surface finish and roughness can interfere with interpretation.
- Reference standards are needed for setup.
- Penetration depth is limited.
- Flaws such as delaminations that lie parallel to the probe coil winding and probe scan direction are undetectable.

Guided Wave Systems

Guided wave systems provide the user the option of interrogating a pipe section that is remotely located from the access location. This feature is attractive for buried piping applications, since it permits below-ground segments to be examined by launching waves from an above-ground location.

The guided wave system induces stress wave modes that travel axially while affecting the complete pipe cross-section. Tool operators can introduce up to three modes of excitation: torsional, flexural, and longitudinal. For buried piping, the torsional mode is most commonly used because of its longer range. Torsional waves are not affected by the presence of water and exhibit less attenuation in coated systems. Flexural and longitudinal modes are appropriate choices for above-ground gas-filled systems, but produce waves that attenuate rapidly in below-ground and water-filled pipes.

In buried pipes, guided waves are reported to have a range of up to 100 feet (30 m), with the distance affected by the type of coating and soil compaction.

Advantages of guided waves include the following:

- They allow examination of buried pipe segments from a convenient above-ground external location.
- They provide accurate longitudinal placement of detected indications and pipe joints.

Disadvantages of guided waves include the following:

- The signals do not lend themselves to accurate sizing of defects.
- The range is affected by coating type and soil compaction.
- The range is limited by elbows, tees, valves, or other pipe features.
- Defects at a close distance from the exciter may not be properly resolved.

The Broadband Electromagnetic Method

The broadband electromagnetic (BEM) method can be used to perform spot thickness measurements inside buried piping. The method has been applied to assessing the condition of bell-and-spigot joints in power plants. However, in principle, the technique can be used to perform thickness measurements anywhere.

The method applies the pulsed eddy current process to probe the pipe condition at a given location while using proprietary software to infer the wall thickness value. Thus, the method is a variant of the Incotest technique currently used to examine above-ground insulated pipes and vessels. The BEM sensors, however, are better designed for deployment in the dirty below-ground environment.

The pulsed eddy current process used by BEM detects the presence of defects by inducing eddy currents on the outside surface of the pipe and monitoring the change in the magnetic field as the currents diffuse and permeate the pipe. The average wall thickness over the footprint of the probe is then measured by recording the time it takes for the currents to diffuse and permeate the pipe wall and comparing it with calibration standards. When performing measurements in contact with the pipe, the areal coverage is approximated by the size of the coil. However, as the coil is lift away from the pipe, the footprint increases significantly, affecting the spatial resolution of the method.

The advantages of the BEM method include the following:

- The probe requires no contact with the pipe.
- It is not affected by the pipe curvature.
- It is not affected by the presence of coatings or silt deposits.
- It is tolerant of lift-off.
- It is tolerant of probe misalignment and rocking.
- It is tolerant of the operator skill level.

The disadvantages of the BEM method include the following:

- Lift-off will affect the spatial resolution.
- It may underestimate wall loss.
- It may miss areas of localized damage.
- It may require recalibration at various pipe joints.

Inspection Using Instrumented Vehicles

Buried piping can be examined by launching vehicles that deliver measurement instrumentation. These vehicles are commonly called *smart pigs*. Pig systems to inspect piping internally for metal loss include ultrasonic, magnetic flux leakage, and remote field eddy current. In addition, internal pipe scanners have been proposed using the broadband electromagnetic method.

Ultrasonic Inspection Vehicles

Piping examination can be performed using vehicles instrumented with ultrasonic sensors. These vehicles are by and large deployed for examination of cross-country hydrocarbon transmission piping. Recently, however, a new vehicle design that is better suited for deployment in power plant piping has been made available commercially. Tools are now available for 6-inch (152-mm) and 8-inch (203-mm) diameter piping. (Performance evaluation of this vehicle was the subject of the EPRI report 1007947 [12].)

The UT instrumented vehicles carry on board an array of 8 or 16 sensors that enable them to assess the pipe wall thickness via the ultrasound pulse-echo technique over a range of several miles.

The UT measurement process, which is analogous to immersion testing, has the advantage of providing a very accurate measure of wall thickness, typically within +/- 0.01 inch. The process, however, requires accurate alignment of the transmitter and receiver sensors and may not record the wall thickness when traversing curved components such as elbows. Loss of data may also occur when the sound wave is affected by scattering, as is likely to happen when surveying heavily corroded areas.

Advantages of the ultrasonic measurement include the following:

- It can provide accurate assessment of wall thickness.
- High spatial resolution can be achieved.
- Very fast data acquisition schemes for high-speed vehicle deployments can be accommodated.

The disadvantages of the technology include the following:

- The method requires extensive internal pipe cleaning.
- Signal loss may occur in corroded areas.
- The method cannot examine elbows.
- It cannot be deployed in the presence of pipe liners.

Magnetic Flux Leakage Inspection Vehicles

Magnetic flux leakage vehicles are the preferred tools for examining hydrocarbon gas transmission pipelines.

Magnetic flux leakage measurement applies a dc magnetic field into the tested pipe section at a sufficient strength to magnetically saturate the metal. This is typically performed with a U-shaped permanent magnet of relatively large size, terminating the poles with brushes made up of ferromagnetic material to enhance the field conduction into the pipe. Sensors, which can be either Hall-effect devices or coils, ride between the poles of the magnet, in close proximity to the pipe surface.

Advantages of the magnetic flux leakage measurement include the following:

- It is a non-contact measurement method—no water or couplant medium is required.
- It can achieve high spatial resolution.
- It is tolerant of small amounts of wall deposits or coating.
- It can accommodate very fast data acquisition schemes for high-speed vehicle deployments.

The disadvantages of the technology include the following:

- Signal interpretation is complex and requires advanced mathematical tools.
- The method exhibits directionally oriented sensitivity.
- The vehicles are bulky and heavy.
- The vehicles require relatively long elbow curvatures for navigation.
- Pipe internal cleaning is required.
- The vehicles cannot be deployed in the presence of pipe liners.

Remote-Field Eddy Current Inspection Vehicles

Remote-field eddy current is the method of choice for inspection of municipal water piping networks because it is tolerant to internal deposits and the presence of liners.

Remote-field eddy current measurement consists of an exciter coil and either a single or multiple receiver elements. The exciter coil typically has a ring shape with a diameter that approximates the pipe's internal diameter. The sensing elements are placed at a sufficient distance from the exciter coil to avoid the influence of the direct eddy current field.

Advantages of the remote field eddy current technique include the following:

- It is a non-contact measurement method—no water or couplant medium is required.
- It is tolerant of significant amounts of wall deposits, coatings, and liners.
- The vehicles can be light, flexible, and able to traverse short-radius elbows.

The disadvantages of the technology include the following:

- The vehicle speed is relatively slow.
- It cannot discriminate between internal and external corrosion.

Remote Detection of Coating Damage

Pipeline coating damage can be detected from above the ground with the electromagnetic potential gradient method.

In this method, a low-frequency current exciter is connected to the pipe, with the ground connection placed some distance away. The instrument operator then walks the pipeline route, mapping the electromagnetic potential field as a function of the distance to the pipe connection. In principle, if the coating is in good condition, a uniform field gradient or attenuation is recorded.

Coating damage affects the field distribution by providing a leak path for the current to return to the ground pole. This leak path appears in the measurement as a sudden change in the attenuation curve. Because nearby metallic structures affect the potential distribution, the method is most effective when performed away from congested areas.

Advantages of the coating survey technique include the following:

- It performs an assessment of the external pipe coating integrity without the need for excavation.
- The method can be used to locate buried pipes and infer their depth.
- The method can be deployed through pavements and road crossings.

The disadvantages of the coating survey technique include the following:

- It provides a qualitative assessment of the coating condition. Information on the real extent of the coating damage is not provided.
- The areas of the disbanded coatings are likely to be underestimated.
- The measurement is influenced by the presence of metallic structures buried nearby.

The Risk-Informed Process Applied to Piping

The following steps can be performed to evaluate a piping system for prioritizing assessment activities utilizing the guidelines outlined in this report.

1. At the outset, all applicable piping systems should be reviewed by knowledgeable personnel to perform a preliminary ranking of these systems based on their criticality and expected impact on safety and plant performance. From this preliminary ranking, the systems deemed to have the greatest potential impact on safety and plant performance should be given the highest priority.
2. Review the systems/components of the highest-priority systems for their design basis, materials of construction, and the service environments that exist.
    - Do environmental stressors such as the presence of water, salt water, soil pH levels below 4, freeze/thaw cycles, or proximity to harsh/corrosive chemicals exist?
    - Will materials impact condition? Is piping coated or lined, and if so, is the coating or lining appropriate for the material and current operational duty?
    - What operational concerns exist? For example, does the piping supply key equipment or transport hazardous materials?

- Are there weighting factors that will affect prioritization of the systems? For example, is the piping normally charged? Can it be isolated in part or totally? Does it affect multiple units?
- Did construction methods (for example, flange assembly, welding, or installation of cathodic protection systems) create potential problems?

3. Review plant and industry history regarding piping failures involving similar materials, designs, construction methods, and environmental conditions. Determine the probable degradation mechanisms that will be experienced (such as mechanical damage, breakage, or chemically initiated corrosion) and expected mean times between failures.
4. Using the above information, determine the cause and effect relationship between degradation mechanisms and the operating environment of the piping systems to determine a probable current condition and expected likelihood of failure. System walkdowns can aid in this evaluation. For a buried piping system utilizing visual inspection methodologies and tools, a probability curve might look like the one shown in Figure 4-1.

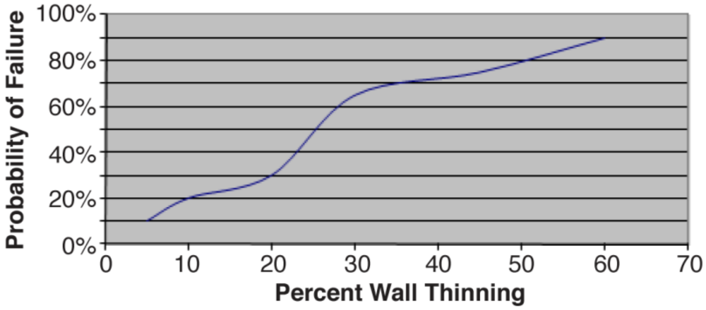

Figure 4-1
Sample probability of failure estimation for piping

5. After determining the expected likelihood of failure of a system or a key component, determine the consequences of component failure. There can be more than one consequence of the failure of a component (for example, lost availability, compromised safety, or repair/replacement costs). In comparing the consequences of one piping failure versus another piping failure (or piping failures versus failures on other key systems) the plant will need to have determined a unit of measure, such as lost generation.
6. Using the results of the probability and consequence analysis, create a risk grid to define the relationship between the probability of failure and the consequence of component failure. The results as depicted on the risk grid will provide guidance in prioritizing condition assessments of the systems based on expected impact to plant performance. Table 4-1 presents some sample risk relationships for cabling systems, and Figure 4-2 presents a sample risk grid based on those relationships.

Table 4-1
Sample risk relationships for piping materials

System	Probability of Failure	Consequence (% Load Loss)
Carbon steel piping	High	60% rated load
Concrete piping	Low	20% rated load
Polymer piping	Low	30% rated load

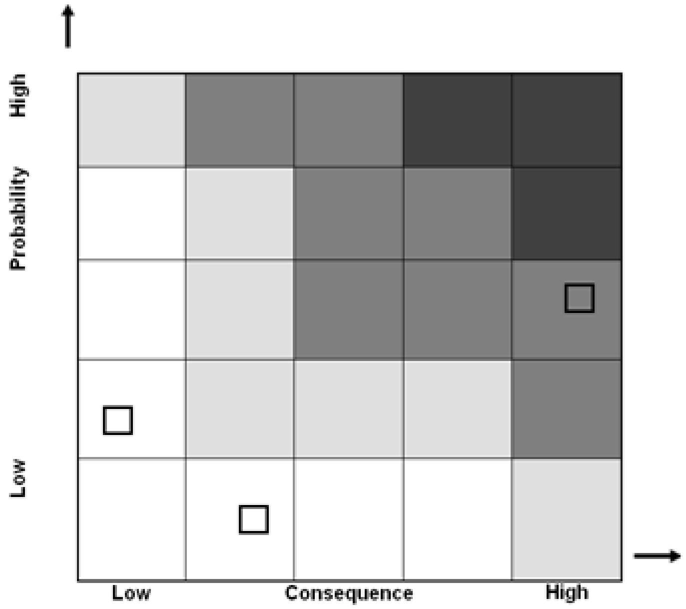

Figure 4-2
Sample risk grid for piping

7. Select the assessment methodology, determine the number of inspection points, and select the inspection points. Considerations should include the following:
    - Level of perceived risk—low/high impact to the selected unit of measure.
    - Cost of inspection/assessment—visual inspection versus pressure testing or ultrasonic thickness testing.
    - Extent and applicability. Do all components in a system require inspection? Is only a portion of the system in a high-risk area such as a harsh environment? Will an assessment of the piping in this area provide a reasonable assessment for the system?
    - Availability of resources and existence of time constraints.
8. After assessment activities have been performed, update the existing risk grids to reflect current data on existing condition, expected likelihood of failure, and consequences of failure.

Section 5: Tanks

Overview

Assessment is performed to determine whether a tank has adequate integrity to prevent leaks or ruptures under normal or upset conditions and whether the tank has been subject to internal or external corrosion.

API Standard 653, "Tank Inspection, Repairs, Alterations, and Reconstruction," provides the minimum requirements for the inspection of tanks [13]. This standard provides a comprehensive in-service inspection checklist. Because the minimum inspection requirements may not be sufficient to prevent a leak, the standard describes methods for augmenting the inspection of tank sections that are in contact with the ground. In brief, a tank inspection program includes the following:

- Visual inspection of the tank internal and external components for the presence of corrosion
- Visual inspection of the tank shell and roof sections, both internally and externally, including the coating condition
- Thickness measurements at any suspected corrosion locations
- Thickness measurements of the shell and roof sections at the plate corners and the plate center to assess the remaining load carrying capacity
- Assessment of shell-to-bottom and plate lap welds for the presence of cracking and leaks
- Volumetric assessment of buried tank shell sections for localized pit detection and sizing
- Volumetric assessment of the tank's bottom floor for localized pit detection and sizing

Tank Inspections

Effective methodologies to determine the condition of tanks depending on accessibility are described in the paragraphs that follow [10].

Visual Inspection

Visual inspection technologies are suitable for detecting areas with deposits, for recognizing severe corrosion damage, and for locating leaks. In addition, video inspection may help identify the prevalent corrosion mechanisms by examining the prevailing metal loss patterns. Video inspection tools are available to examine either flooded or drained tank systems.

As discussed in Section 4, tools to assist in visual inspections include fiberscopes, borescopes, crawlers, and submersibles.

During visual examination, important details can be collected that may be useful for future analysis and for deciding on the type of NDE to be used for further analysis. Visual inspection should be carried out as a complementary method to other NDE methods. In performing visual checks it is important to know the type of defect that can develop and to recognize the areas in which failures can occur.

Visual examination of plant system components by an experienced inspector can reveal the following information:

- General condition of the component
- Presence of a leak and other abnormal operation conditions
- Presence or absence of surface deposits (such as oxide films or corrosive product on the surface), scaling, corrosion, erosion, discoloration, and oxidation bulging
- Presence or absence of cracks, orientation of cracks, and position of cracks relative to the various zones in the case of welds
- Surface porosity, unfilled craters, contour of the weld beads, and probable orientation of the interface between the fused weld bead and the adjoining parent metal
- Potential sources of mechanical weakness, such as sharp notches or misalignment
- Missing parts, dimensional conformances, gross defects visible on the surface, and distortion during fabrication and in service

Plate Wall Thickness—Ultrasonic Testing

As discussed in Section 4, ultrasonic testing is the most widely used NDE method for the detection and characterization of corrosion and cracks. It can be used on many materials, including metals, plastics, composites, fiberglass, ceramics, and glass. It can be used to accurately measure material wall thickness or identify imperfections. As noted previously, a significant advantage of ultrasonic testing is that access to only one surface is needed.

Advantages of ultrasonic testing include the following:

- It can provide accurate thickness measurements.
- Only single-sided access is needed when the pulse-echo technique is used.
- The depth of penetration for flaw detection or measurement is superior to that of other NDE methods.
- It is accurate in determining reflector position and estimating size and shapes.
- It provides essentially instantaneous results.
- Detailed images can be produced with automated systems.
- It can be made to be sensitive to detection of in-service discontinuities such as cracks.

Disadvantages of ultrasonic testing include the following:

- At least one surface must be accessible to transmit ultrasound into the material.
- Techniques can be complex and thus require highly skilled personnel and procedures.
- Surface finish must be adequate to promote transmission of ultrasonic energy into the material.
- It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.

Volumetric Assessment of Tank Bottom and Shell Plate

Ultrasonic Testing

As discussed earlier, ultrasonic testing provides an accurate measurement of remaining wall thickness traceable to a standard.

Electromagnetic Assessment of Tank Bottom and Shell Plate

Electromagnetic techniques do not require couplant and therefore are not as susceptible to loss of data due to loss of contact with the tank surface. In addition, it is not necessary for the sensor to pass directly over the top of a pit to sense the anomaly. This enables electromagnetic techniques to scan faster and with more coverage, as compared to ultrasonic testing. On the other hand, electromagnetic techniques do not exhibit sufficient depth sizing accuracy to be used as a standalone measurement. It is common practice to use electromagnetic assessment for detection only, marking the areas of concern on the plates and manually establishing the depths of indications with manually applied ultrasonic tests. There are three electromagnetic methods offered by vendors for volumetric examination of tank plates:

- **Magnetic flux leakage.** This method uses U-shaped magnets to saturate the metal between the poles with a dc field. Sensors are placed between the poles to detect the magnetic field distortions caused by the presence of pits. Plate areas marked with field amplitude changes are marked for further examination with UT.
- **Low-frequency electromagnetics.** This method also uses a U-shaped magnet, but an ac magnetic field at low frequency is used instead. Phase changes in the acquired signal are primarily used to identify indications for further evaluation.
- **Slofec technique.** In this method, a dc magnetic field is used to saturate the test plate section, but rather than using a passive detector, the method places active low-frequency eddy current coils between the poles. Standard eddy current analysis of amplitude and phase are used to pinpoint plate areas for verification.

Weld Assessment

Magnetic Particle Technique

The magnetic particle technique requires careful surface preparation, and the potentially extensive weld surface available in a tank makes implementing this approach challenging.

Electromagnetic Techniques

Electromagnetic techniques require minimal surface cleaning, are tolerant of the presence of dirt and small amounts of lift-off, and can be deployed at scanning speeds of up to 1 foot (300 mm) per second. There are two principal electromagnetics techniques:

- **Eddy current balanced field.** This method deploys a transmitter and a receiver coil arrangement with the coils perpendicular to each other. The coils are balanced so that if no flaws are present a null signal is obtained. The exciter induces an alternating magnetic field on the weld surface. The presence of an anomaly causes a change in the magnetic field surface distribution that is detected and analyzed for amplitude and phase variations.
- **Alternating current field measurement.** With this method, an alternating surface current is induced in the component. The presence of a surface-breaking crack changes the current distribution and its associated magnetic fields. The changes in the magnetic field are detected and interpreted to infer the presence of the crack.

The Risk-Informed Process Applied to Tanks

The following steps can be performed to evaluate a tank system for prioritizing assessment activities utilizing the guidelines outlined in this report.

1. At the outset, all applicable tank systems should be reviewed by knowledgeable personnel to perform a preliminary ranking of these systems based on their criticality and expected impact on safety and plant performance. From this preliminary ranking, the systems deemed to have the greatest potential impact on safety and plant performance should be given the highest priority.
2. Review the systems/components of the highest-priority systems for their design basis, materials of construction, and the service environments that exist.
    - Do environmental stressors such as the presence of water, salt water, soil pH levels below 4, freeze/thaw cycles, or proximity to harsh/corrosive chemicals exist?
    - Will materials impact condition? For example, is the tank coated or lined, and if so, is the coating or lining appropriate for the material and current operational duty?
    - What operational concerns exist? For example, does the tank serve key equipment or store hazardous materials?
    - Are there weighting factors that will affect prioritization of the systems? For example, is the tank normally filled? Can it be isolated? Does it affect multiple units?
    - Did construction methods (for example, flange assembly, welding, or installation of cathodic protection systems) create potential problems?
3. Review plant and industry history regarding tank failures involving similar materials, designs, construction methods, and environmental conditions. Determine the probable degradation mechanisms that will be experienced (such as mechanical damage, coating degradation, or chemically initiated corrosion) and expected mean times between failures.
4. Using the above information, determine the cause and effect relationship between degradation mechanisms and the operating environment of the piping systems to determine a probable current condition and expected likelihood of failure. System walkdowns can aid in this evaluation. For a buried tank system utilizing visual inspection methodologies and tools, a probability curve might look like one shown in Figure 5-1.

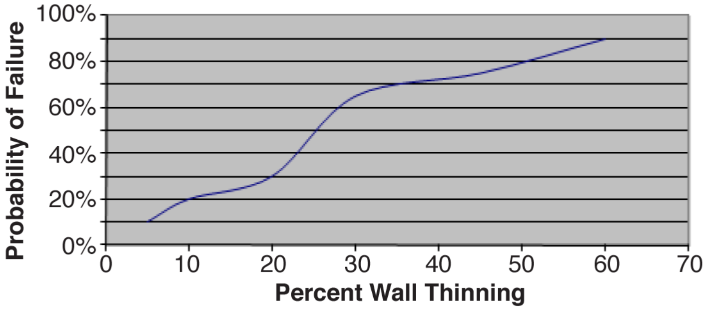

Figure 5-1
Sample probability of failure estimation for tanks

5. After determining the expected likelihood of failure of a system or a key component, determine the consequences of component failure. There can be more than one consequence of the failure of a component (for example, lost availability, compromised safety, or repair/replacement costs). In comparing the consequences of one tank failure versus another tank failure (or tank failures versus failures on other key systems), the plant will need to have determined a unit of measure, such as lost generation.
6. Using the results of the probability and consequence analysis, create a risk grid to define the relationship between the probability of failure and the consequence of component failure. The results as depicted on the risk grid will provide guidance in prioritizing condition assessments of the systems based on expected impact to plant performance. Table 5-1 presents some sample risk relationships for tank materials, and Figure 5-2 presents a sample risk grid based on those relationships.

Table 5-1
Sample risk relationships for various tank materials

System	Probability of Failure	Consequence (% Load Loss)
Carbon steel	High	60% rated load
Fiberglass	Low	20% rated load
Polymer	Low	30% rated load

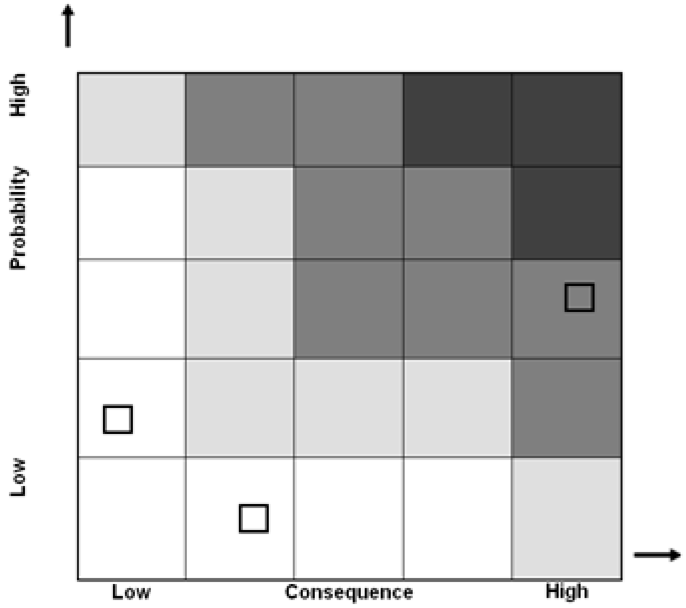

Figure 5-2
Sample risk grid for tanks

7. Select the assessment methodology, determine the number of inspection points, and select the inspection points. Considerations should include the following:
    - Level of perceived risk—low/high impact to the selected unit of measure.
    - Cost of inspection/assessment—visual inspection versus vacuum testing or ultrasonic thickness testing.
    - Extent and applicability. Do all components in a system (including walls, anchor bolts, and flange supports) require inspection? Will an assessment of the tank in this area provide a reasonable assessment for other tanks in similar service?
    - Availability of resources and existence of time constraints.
8. After assessment activities have been performed, update the existing risk grids to reflect current data on existing condition, expected likelihood of failure, and consequences of failure.

Section 6: Chimneys and Stacks

Overview

Generally, the term *chimney* is used to refer to reinforced concrete or brick shell construction, and the term *stack* is used to refer to steel or fiber-reinforced plastic (FRP) shell construction. Each chimney or stack is a unique structure subjected to aggressive operating and natural environments and subject to degradation over time. Utility chimneys are typically exposed to severe environmental conditions (chemical attack, high operating temperatures, extreme ambient temperatures, vibration, earthquakes, and high wind loads). They are also often subjected to operating conditions that change over time (such as fuel switching, duty cycling, structural modifications, and changes to environmental control processes). Proper and timely inspections can help ensure that the structural integrity of the chimney is maintained, minimizing maintenance expenditures and outage exposure.

The scope and frequency of inspections will vary with a number of factors, such as chimney type, age, outage schedule, initial operating conditions, exhaust gas conditions (composition, temperature, and humidity), changes in operating condition, visible degradation, and the importance and safety of the chimney. Recommended inspections are divided into three classes, with recommended frequencies for each. Actual inspection frequencies should be determined based on observations and the experience of plant personnel performing the inspections. It is important to keep in mind that the proper selection of inspection procedures and the performance of the inspections should be carried out by personnel experienced in the design and construction of chimneys.

It is also important to note that many chimneys may contain hazardous materials such as asbestos, lead-based paints, and the toxins found in ash deposits. If there is reason to suspect that such materials may be present and personnel could be exposed to them, then proper sampling and analysis of the materials should be performed in accordance with Occupational Health and Safety (OSHA) regulations. Appropriate personal protective equipment should always be utilized.

Chimney and Stack Inspections

Inspection and assessment activities to determine the condition of stacks and chimneys are described in the paragraphs that follow [14].

Class I Inspections

Class I inspections are routine inspections that should be performed at regular intervals of between 6 and 24 months. A Class I inspection is primarily a visual inspection. The exterior of the chimney should be visually inspected, using binoculars or a spotter scope from the ground and any nearby vantage points such as building roofs, catwalks, or adjacent chimney ladders and platforms. Observations should be made for signs of deterioration such as fallen debris, new cracks, spalled or crumbling concrete or brickwork, corrosion or wear of exposed metal and appurtenances, or blistering or discoloration of FRP sections.

Although a Class I inspection can be performed with the chimney on line, it is preferable, whenever possible, to perform the inspection with the chimney off line, to permit access for a full-height inspection of the liner interior and as much of the annular space as is accessible. Safety inspections of ladders, platforms, and stairs should also be performed.

Visual inspection procedures are inherently subjective. One observer may assess the degree of discoloration or a roughening of a surface differently than another observer. Similarly, photographs of the same part of a structure can appear different if taken under different ambient light conditions. Quantification of observations is therefore important, and the use of nondestructive tests, measurements, and laboratory assessment of material samples can greatly enhance the objectivity of an inspection and subsequent condition assessment.

Class II Inspections

Class II inspections should be performed at regular intervals in the range of 2 to 5 years, and alternated with Class I inspections. A Class II inspection should be performed with the chimney off line, and will include all of the work performed for the Class I inspection, plus a full-height interior inspection. Depending on the chimney condition and type, a Class II inspection may also include the following:

- Full- or partial-thickness core samples of concrete or brick for laboratory assessment of acid attack, material degradation, remaining strength, and corrosion susceptibility.
- Nondestructive assessment of thickness and weld condition of steel chimneys and flue liners.
- Nondestructive assessment of FRP liners.
- Installation of crack monitoring equipment on concrete and brick chimneys.
- Full-height inspection of the chimney exterior, particularly to provide direct access to normally inaccessible portions of the chimney, using multiple drops as necessary.

Class III Inspections

A Class III inspection is not routine. It is performed only when significant degradation of any structural component has occurred, as indicated by the results of Class I or Class II inspections, or when the chimney has experienced an unusual event such as the following:

- An earthquake
- Hurricane- or tornado-strength winds
- An explosion, implosion, or significant impact
- Fire or overheating
- Flooding through failure or leakage of wet precipitation or scrubber systems
- Local modifications that may change performance and applied loads, such as changed air flow and vortex shedding by a new neighboring chimney

After such an event, a Class I inspection should be performed immediately, to determine the need for additional inspection and repair, or to clear the chimney for continued use.

A Class III inspection would include the following:

- Inspection of all parts of a chimney available for a Class II inspection, depending on whether the chimney is on line or off line
- Nondestructive integrity testing
- Removal of cored or drilled samples of material for physical and chemical analysis

A Class III inspection should also be performed before any significant structural modifications to a chimney or liner, such as an increase in height or installation of platforms or breechings.

The Risk-Informed Process Applied to Chimneys and Stacks

The following steps can be performed to evaluate a chimney or stack for prioritizing assessment activities utilizing the guidelines outlined in this report.

1. At the outset, all applicable chimneys and stacks should be reviewed by knowledgeable personnel to perform a preliminary ranking of these systems based on their criticality and expected impact on safety and plant performance. From this preliminary ranking, the systems deemed to have the greatest potential impact on safety and plant performance should be given the highest priority.

2. Review the systems/components of the highest-priority structures for their design basis, materials of construction, and the service environments that exist.
   - Do environmental stressors such as high operating temperatures, extreme ambient temperatures, rapid heating, vibration, or high wind loads exist?
   - Will materials impact condition? What materials of construction were used, and are they still appropriate for the current operational conditions?
   - Have operational conditions changed over time—for example, because of fuel switching, duty cycling, or changes to the environmental control processes?
   - Are there weighting factors that will affect prioritization of the systems? For example, is the structure serving multiple units? Are any units baseloaded?
   - Did construction methods create potential problems with regard to any change in operating conditions, or are there any structural changes to the chimney or stack?
3. Review plant and industry history regarding chimney and stack failures involving similar materials, design, construction method, and environmental conditions. Determine the probable degradation mechanisms that will be experienced (such as chemical attack, mechanical damage, coating degradation, corrosion, or weathering) and expected mean times between failures.
4. Using the above information, determine the cause and effect relationship between degradation mechanisms and the operating environment of the chimney or stack to determine a probable current condition and expected likelihood of failure. System walkdowns can aid in this evaluation. For a steel chimney utilizing visual inspection methodologies and nondestructive assessment of material thickness, a probability curve might look like the one shown in Figure 6-1.

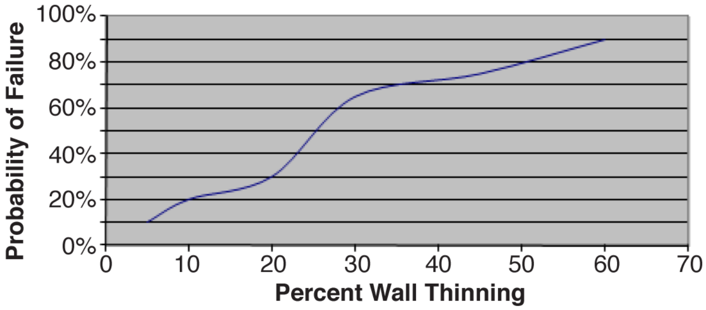

Figure 6-1
Sample probability of failure estimation for chimneys

5. After determining the expected likelihood of failure of a system or a key component, determine the consequences of component failure. There can be more than one consequence of the failure of a component (for example, lost availability, compromised safety, or repair/replacement costs). In comparing the consequences of one chimney or stack failure versus another chimney or stack failure (or chimney or stack failures versus failures on other key systems) the plant will need to have determined a unit of measure, such as lost generation.
6. Using the results of the probability and consequence analysis, create a risk grid to define the relationship between the probability of failure and the consequence of component failure. The results as depicted on the risk grid will provide guidance in prioritizing condition assessments of the systems based on expected impact to plant performance. Table 6-1 presents some sample risk relationships for chimneys and stacks, and Figure 6-2 presents a sample risk grid based on those relationships.

Table 6-1
Sample risk relationships for chimneys and stacks

System	Probability of Failure	Consequence (% Load Loss)
Reinforced concrete stack	Low	60% rated load
Fiber-reinforced stack	Low	20% rated load
Steel chimney	High	60% rated load

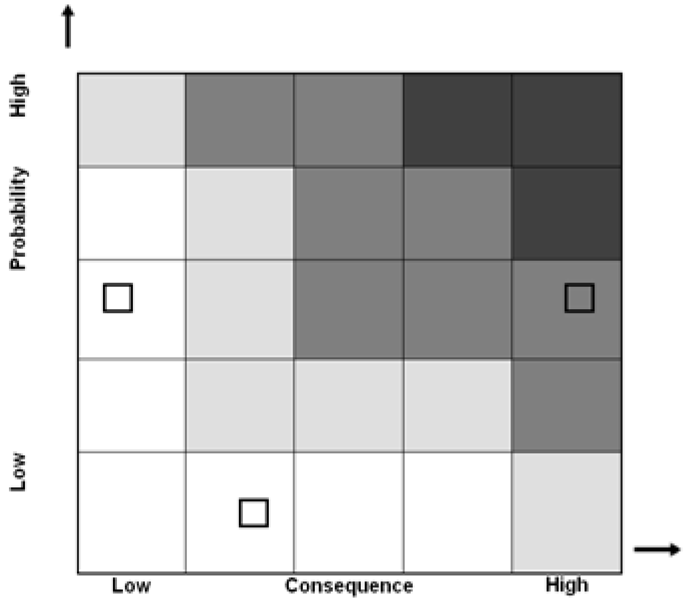

Figure 6-2
Sample risk grid for chimneys and stacks

7. Select the assessment methodology, determine the number of inspection points, and select the inspection points. Considerations should include the following:
    - Level of perceived risk—low/high impact to the selected unit of measure.
    - Cost of inspection/assessment—visual inspection versus core sampling or ultrasonic thickness testing.
    - Applicability. Will an assessment of the chimney in this area provide a reasonable assessment for other chimneys in similar service?
    - Availability of resources and existence of time constraints.
8. After assessment activities have been performed, update the existing risk grids to reflect current data on existing condition, expected likelihood of failure, and consequences of failure.

Section 7: Ash Ponds and Dam Structures

Overview

Dams are barriers designed to contain fluids and are subject to erosion, corrosion, and deterioration by wind, rain, ice, and temperature. Water passing over, under, and through dams can weaken these structures over time. Regular inspections are vital to the proper care and maintenance of dams and are essential to preserving the integrity of the structure and avoiding costly repairs.

Inspections are needed to ensure that no unsafe conditions are developing due to weather, animal activity, or vandalism. Fences, handrails, gates, access roads, bridges, and warning signs serve to improve access and personal safety. Fences also discourage vandalism.

An inspection by a qualified engineer provides a thorough, systematic evaluation of the condition of the structure. Such inspections should be performed whenever potentially significant defects such as the following are first observed:

- Earth slides in the embankment
- Uncontrolled seepage from the dam
- Severe erosion of spillways or discharge channels
- Seepage around pipes
- Concrete deterioration (cracks and joint displacement)
- Pipe joint separation or damage
- Surface cracking
- Irregular settlement
- Sinkholes

Ash Pond and Dam Inspections

Inspection and assessment activities for determining the condition of fluid retaining structures are described in the paragraphs that follow [15,16].

Settlement

Embankments and downstream toe areas should be examined for any evidence of unusual localized or overall settlement, depressions, or sinkholes.

Slope Stability

Embankment slopes should be examined for irregularities in alignment and variances from originally constructed slopes, for unusual changes from original crest alignment and elevation, for evidence of movement at or beyond the toe, and for surface cracks that indicate significant internal movement.

Seepage

The downstream face of abutments, embankment slopes and toes, embankment-structure contacts, and downstream valley areas should be examined for evidence of existing or past seepage. The sources of seepage should be investigated to determine the cause and the potential severity of effects on dam safety under all operating conditions. Animal burrows and vegetative growth on slopes that might cause detrimental seepage should be examined.

Drainage Systems

All drainage systems should be examined to determine whether the systems can freely pass discharge and to ensure that the discharge is not carrying embankment or foundation material. Systems used to monitor drainage should be examined to ensure that they are operating correctly.

Slope Protection

The slope protection should be examined for erosion-formed gullies and wave-formed notches and benches that have reduced the embankment cross-section or exposed less wave-resistant materials. The adequacy of slope protection against waves, currents, and surface runoff that may occur at the site should be evaluated, when pertinent.

The Risk-Informed Process Applied to Ash Ponds and Dams

The following steps can be performed to evaluate a dam for prioritizing assessment activities utilizing the guidelines outlined in this report.

1. At the outset, all applicable dams should be reviewed by knowledgeable personnel to perform a preliminary ranking of these systems based on their criticality and expected impact on safety and plant performance. From this preliminary ranking, the systems deemed to have the greatest potential impact on safety and plant performance should be given the highest priority.
2. Review the systems/components of the highest-priority systems for their design basis, materials of construction, and the service environments that exist.
    - Do environmental stressors such as weathering, animal activity, or brush/tree growth exist?

- Will materials impact condition? Is the dam built of earth, rock, masonry, or steel? Are those materials appropriate for current operational duty?
- What operational concerns exist—for example, could failure of the dam potentially result in loss of life or damage to off-site property?
- Are there weighting factors that will affect prioritization of the systems—for example, environmental or regulatory concerns?
- Did construction methods create potential problems from slides, settlement, or seepage?

3. Review plant and industry history regarding dam failures involving similar materials, design, construction methods, and environmental conditions. Determine the probable degradation mechanisms that will be experienced (such as erosion, corrosion, or deterioration by wind, rain, ice, and temperature) and expected mean times between failures.

4. Using the above information, determine the cause and effect relationship between degradation mechanisms and the operating environment of the dam to determine a probable current condition and expected likelihood of failure. Walkdowns can aid in this evaluation. For a dam utilizing visual inspection methodologies, a probability curve might look like the one shown in Figure 7-1.

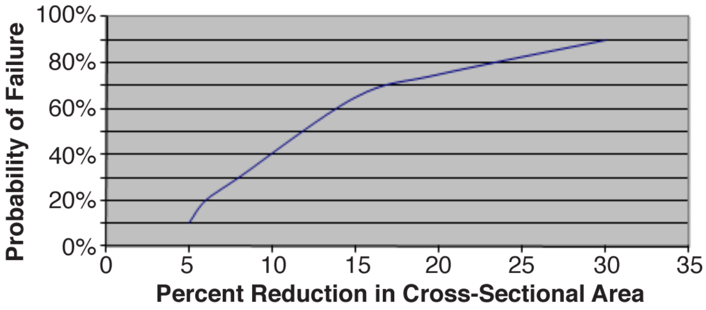

Figure 7-1
Sample probability of failure estimation for a dam structure

5. After determining the expected likelihood of failure of a system or a key component, determine the consequences of component failure. There can be more than one consequence of the failure of a component (for example, lost availability, compromised safety, or repair/replacement costs). In comparing the consequence of one dam failure versus another dam failure (or dam failures versus failures on other key systems) the plant will need to have determined a unit of measure, such as lost generation.

6. Using the results of the probability and consequence analysis, create a risk grid to define the relationship between the probability of failure and the consequence of component failure. The results as depicted on the risk grid will provide guidance in prioritizing condition assessments of the systems based on expected impact to plant performance. Table 7-1 presents some sample risk relationships for dam structures, and Figure 7-2 presents a sample grid based on those relationships.

Table 7-1
Sample risk relationships for dam structures

System	Probability of Failure	Consequence (% Load Loss)
Masonry	Low	30% rated load
Earth	Medium	20% rated load
Steel	Low	20% rated load

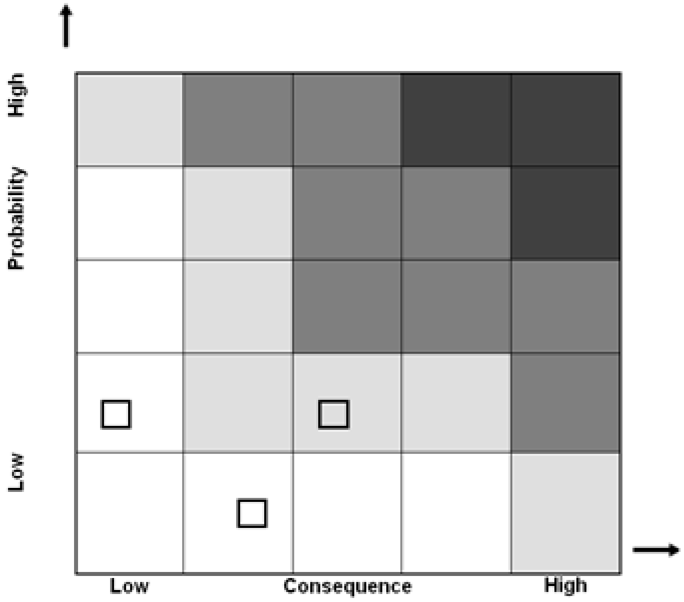

Figure 7-2
Sample risk grid for dam structures

7. Select the assessment methodology, determine the number of inspection points, and select the inspection points. Considerations should include the following:
    - Level of perceived risk—low/high impact to the selected unit of measure.
    - Cost of inspection/assessment—visual inspection versus civil testing by a third-party engineering firm.
    - Specialized nature of the work. Do site personnel have the expertise to conduct dam inspections?
    - Availability of resources and existence of time constraints.
8. After assessment activities have been performed, update the existing risk grids to reflect current data on existing condition, expected likelihood of failure, and consequences of failure.

Section 8: Building Structures

Overview

Process, administrative, and support facilities and related infrastructure, although not directly related to the generation of electricity, are important in supporting the operation of a power plant. Often, maintenance on these structures has been deferred, providing the potential for significant structural degradation.

These structures are acted upon by many different forces such as dead weight of objects, movement of objects, expansion or contraction due to temperature, and swelling or shrinkage due to moisture changes. Every structure must resist both dead and live loads. For example, consider an administrative services building—on any given floor there is a live load made up of the people and furnishings and a dead load made up of the finished floor material.

When subjected to a load, a structure or structural element twists, curves, stretches, shortens, and/or sags, potentially assuming some new configuration as stresses accumulate in the material. Some types of deformation can be observed visually, while others can be detected only by using measuring devices. The type of deformation can be a clue as to the types of stresses that are being produced to cause material deformation. It is normal for stress and deformation to occur up to a certain limit, depending on the type of material being used. When an overstressed condition is induced in any material, it reacts by breaking down physically, thus impairing its ability to carry the induced load. Inspection personnel must be able to relate the type of deformation and its location on the structural element to the basic type of stress causing it in order to evaluate whether the resulting deterioration is evidence of a potential structural failure.

Building Structure Inspections

Inspection guidelines for the most common types of structures are presented in the paragraphs that follow [17].

Reinforced Concrete

Slabs on Grade

- Check for overall watertightness and locate any leaks that may be present. Leaks can signify cracks or excessive hydrostatic pressure.
- Check the general appearance of foundation wall or substructure for any stress-related conditions. Categorize the type of stress—tension, compression, shear, or bending/buckling.
- Check for uneven settlement.
- Check for uplift or the presence of hydrostatic pressure causing upward movement of existing grade, foundation wall, or slab.
- Check the slab for any structural modifications, new equipment on old slabs, old equipment since removed, subslab pits (new or filled in) and traffic usage changes.
- Check for exposure conditions, specifically chemical attack and freeze/thaw action.
- Check all previous repairs for any possible cracking or deterioration.

Cast-In-Place Concrete Beams and Columns

- Check general appearance for any stress-related conditions—tension, compression, shear, or bending/buckling.
- Check for uneven settling by observing the condition of the existing grade on the exterior or the condition of the foundation slab.
- For columns, check for uplift or the presence of hydrostatic pressure causing upward movement of the existing grade or slab.
- Check for exposure conditions, specifically chemical attack, impact exposure, efflorescence, staining and rust, dusting, surface deterioration, decay, or splitting.
- Check all previous repairs for any possible cracking or deterioration.
- Check any exposed reinforcement and evaluate the extent of rust or deterioration.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.

Loaded Precast Concrete Beams and Columns

- Check general appearance for any stress-related conditions—tension, compression, shear, or bending/buckling.
- Check for uneven settling by observing the condition of the existing grade on the exterior or the condition of the foundation slab.
- Check for improper design and construction conditions that can cause deficiencies such as cracking and surface deterioration.

- For columns, check for uplift or the presence of hydrostatic pressure causing upward movement of the existing grade or slab.
- Check for exposure conditions, specifically chemical attack, impact exposure, efflorescence, staining and rust, dusting, surface deterioration, decay, or splitting.
- Check all previous repairs for any possible cracking or deterioration.
- Check any exposed reinforcement and evaluate the extent of rust or deterioration.
- Check for any improperly designed or placed anchorage components. Verify that anchorage is intact and properly tightened.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.

Structural Steel

Beams and Columns

- Check general appearance for any stress-related conditions—tension, compression, shear, or bending/buckling.
- Check for uneven settling by observing the condition of the existing grade on the exterior or the condition of the foundation slab.
- For columns, check for uplift or the presence of hydrostatic pressure causing upward movement of the existing grade or slab.
- Check for exposure conditions, specifically chemical attack, impact exposure, efflorescence, staining and rust, dusting, surface deterioration, decay, or splitting.
- Check all previous repairs for any possible cracking or deterioration.
- Check for improper or damaged welds and lamellar tearing of weld joints.
- Check condition of anchorage to verify that it is intact and properly tightened.
- Check bearing plates for proper bearing, anchorage, and deterioration status.

Pre-Engineered Metal Building Systems

- Check general appearance for any stress-related conditions—tension, compression, shear, or bending.
- Check for uneven settling by observing the condition of the existing grade on the exterior or the condition of the foundation slab.
- Check for improper design and construction conditions that can cause deficiencies.
- Check bearing plates for proper bearing, anchorage, and deterioration status.
- Check structural members for level or plumb and true.

- For columns, check for uplift or the presence of hydrostatic pressure causing upward movement of the existing grade or slab.
- Check for exposure conditions, specifically chemical attack, impact exposure, efflorescence, staining and rust, dusting, surface deterioration, decay, or splitting.
- Check all previous repairs for any possible cracking or deterioration.
- Check for improper or damaged welds and lamellar tearing of weld joints.
- Check condition of fasteners and bolts to verify that they are intact and properly tightened.
- Check all bracing and tie rods for damage and tightness.
- Check for watertightness or extent of leaks.
- Check moisture strips and joint sealants for damage and/or deterioration.
- Check bearing plates for proper bearing, anchorage, and deterioration status.

General Structural Members (Trusses, Joists, Decking, Bracing, and Platform Supports)

Inspect for general cleanliness and check for the following:

- Cracks
- Localized distortion
- Failure of paint or other protective coating
- Unusual wear such as impact failure
- Misalignment
- Plumb of vertical members
- Corrosion
- Stress marks appearing on coating

Connections

Inspect for general cleanliness and check for the following:

- Corrosion
- Loosening of bolts and or rivets
- Cracks in welds
- Localized distortion
- Unusual wear such as destruction of bolt threads
- Protective coating failure

Wood/Timber

Wood Beams and Columns

- Check general appearance for any stress-related conditions—tension, compression, shear, or bending/buckling.
- Check for uneven settling by observing the condition of the existing grade on the exterior or the condition of the foundation slab.
- Check for improper design and construction conditions that can cause deficiencies.
- For columns, check for uplift or the presence of hydrostatic pressure causing upward movement of the existing grade or slab.
- Check for exposure conditions, specifically chemical attack, impact exposure, staining, dry rot, surface deterioration, decay, or splitting.
- Check all previous repairs for any possible cracking or deterioration.
- Check for any improperly designed or placed anchorage components. Verify that anchorage is intact and properly tightened.
- Check for splitting, cracking, or deterioration of surfaces.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.

Pre-Engineered Wood Building Systems

- Check general appearance for any stress-related conditions—tension, compression, shear, or bending/buckling.
- Check for uneven settling by observing the condition of the existing grade on the exterior or the condition of the foundation slab.
- Check bearing plates and anchor bolts for proper anchorage, bearing, and deterioration status.
- Check structural members for level or plumb and true.
- Check for water damage or spongy/soft areas.
- Check for fire- or heat-damaged surfaces resulting in deteriorated areas.
- Check for improper design and construction conditions that can cause deficiencies such as cracking and surface deterioration.
- For columns, check for uplift or the presence of hydrostatic pressure causing upward movement of the existing grade or slab.
- Check for exposure conditions, specifically chemical attack, impact exposure, staining, dry rot, surface deterioration, decay, or splitting.
- Check all previous repairs for any possible cracking or deterioration.
- Check for any improperly designed or placed anchorage components. Verify that anchorage is intact and properly tightened.

- Check for splitting, cracking, or deterioration of surfaces.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.

General Wood/Timber Components (Sills, Plates, Rafters Joists, Headers, Trusses, Studs, Subfloors, and Fascia)

Inspect for general cleanliness and look for the following:

- Decay
- Marine borers
- Insect damage
- Rodent damage
- Fire damage
- Splitting
- Checking
- Misalignment
- Unsoundness of wood
- Loosened laminate
- Loosened connections
- Holes in wood

The Risk-Informed Process Applied to Building Structures

The following steps can be performed to evaluate a building structure for prioritizing assessment activities utilizing the guidelines outlined in this report.

1. At the outset, all applicable building structures should be reviewed by knowledgeable personnel to perform a preliminary ranking of these systems based on their criticality and expected impact on safety and plant performance. From this preliminary ranking, the systems deemed to have the greatest potential impact on safety and plant performance should be given the highest priority.
2. Review the systems/components of the highest-priority systems for their design basis, materials of construction, and the service environments that exist.
    - Do environmental stressors such as weathering, presence of moisture or salt water, improper ventilation, or wind loads exist?
    - Will materials impact condition? Are they suitable for the current function and environment? Are proper coatings used and will the materials support existing live loads?

- What operational concerns exist? For example, is there the potential for uneven settling, swelling, or shrinkage due to moisture changes or thermal expansion?
- Are there weighting factors that will affect prioritization of the systems—for example, the structure's function or the function of the equipment or personnel housed in the structure?
- Did faulty construction methods such as improper coatings or finishes, welding techniques, or concrete composition create potential problems?

3. Review plant and industry history regarding structure failures involving similar materials, design, construction methods, and environmental conditions. Determine the probable degradation mechanisms that will be experienced (such as mechanical damage, corrosion, decay, or weathering) and expected mean times between failures.
4. Using the above information, determine the cause and effect relationship between degradation mechanisms and the operating environment of the structures to determine a probable current condition and expected likelihood of failure. Walkdowns can aid in this evaluation. For a concrete structure such as a slab or column being inspected for honeycombing (surface defects and voids), a probability curve might look like the one shown in Figure 8-1.

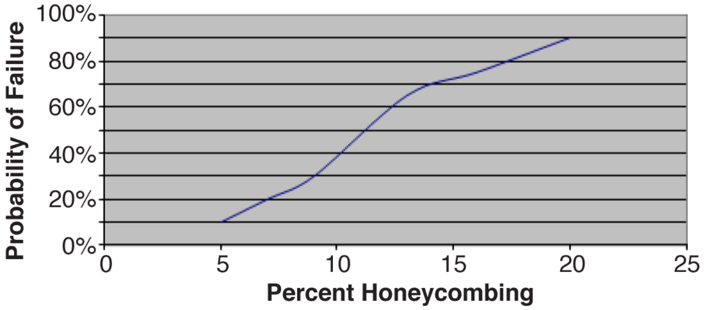

Figure 8-1
Sample probability of failure estimation for a concrete slab or column

5. After determining the expected likelihood of failure of a system or a key component, determine the consequences of component failure. There can be more than one consequence of the failure of a component (for example, lost availability, compromised safety, or repair/replacement costs). In comparing the consequences of one structure failure versus another structure failure (or structure failures versus failures on other key systems) the plant will need to have determined a unit of measure, such as lost generation.
6. Using the results of the probability and consequence analysis, create a risk grid to define the relationship between the probability of failure and the consequence of component failure. The results as depicted on the risk grid will provide guidance in prioritizing condition assessments of the systems based on expected impact to plant performance. Table 8-1 presents some sample risk relationships for building structures, and Figure 8-2 presents a sample risk grid based on those relationships.

Table 8-1
Sample risk relationships for building structures

System	Probability of Failure	Consequence (% Load Loss)
Steel building column	High	30% rated load
Concrete foundation	Low	20% rated load
Wooden beam	High	10% rated load

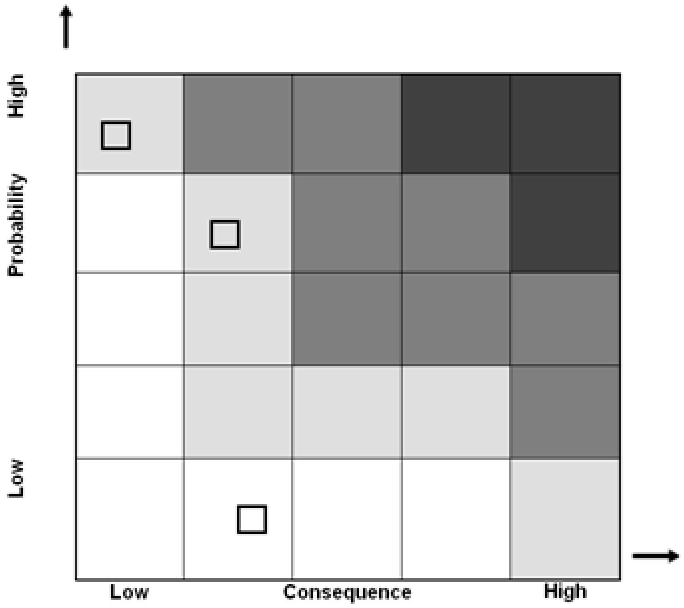

Figure 8-2
Sample risk grid for building structures

7. Select the assessment methodology, determine the number of inspection points, and select the inspection points. Considerations should include the following:
   - Level of perceived risk—low/high impact to the selected unit of measure.
   - Cost of inspection/assessment—visual inspection versus weld testing or insect infestation testing.
   - Extent and applicability. Do all components in a system require inspection? Is only a portion of the system in a high-risk area such as a location with a harsh environment? Will an assessment of the structure in this area provide a reasonable assessment for other structures in the same environment utilizing similar materials?
   - Availability of resources and existence of time constraints.
8. After assessment activities have been performed, update the existing risk grids to reflect current data on existing condition, expected likelihood of failure, and consequences of failure.

Section 9: Cooling Towers

Overview

A counter-flow cooling tower consists of the following elements:

- A concrete, fiberglass, or wood framework with fiber-reinforced, plastic, or corrugated siding
- A system of water distribution pipes and nozzles within the framework
- A heat exchange medium (the fill) made up of modular PVC material
- A basin to collect the cooled water and direct it back to the circulating pumps
- Fans to move the air necessary for proper heat exchange
- Drift eliminator medium to prevent droplets from escaping from the tower in the air flow

Cooling Tower Inspections

The following are guidelines for inspecting a counter-flow cooling tower:

- Check temperature and level instrumentation for proper operation.
- Note any unusual noise or vibration in the tower.
- Inspect the tower frame for cracks, corrosion, wood rot, and other physical damage.
- Check the basin for corrosion and leakage.
- Check access plates for signs of leakage.
- Check the basin level control for damage or defects.
- Check the tower fill and eliminators for damage, missing sections, or collapse.
- Inspect the fan assembly for cracks, corrosion, or other physical damage.
- Check the tower top for missing or blocked distribution nozzles and missing or damaged inspection covers.
- Examine valves for leakage and excessive corrosion. Note damage to operating mechanisms.
- Check tower and piping supports for loose, damaged, or missing fasteners.

- Examine integral equipment controls and wiring.
- Check conduits, control housings, and panels for corrosion or leakage.
- Check the lightning protection system for proper operation.
- Check casing for damage allowing uncontrolled air intake.
- Check the condition of coatings where corrosion and deterioration may be occurring.
- Check drive shaft couplings for cracked bushings, loose bolts, and misalignment.

The Risk-Informed Process Applied to Cooling Towers

The following steps can be performed to evaluate cooling towers for prioritizing assessment activities utilizing the guidelines outlined in this report.

1. At the outset, all applicable cooling towers should be reviewed by knowledgeable personnel to perform a preliminary ranking of these systems based on their criticality and expected impact on safety and plant performance. From this preliminary ranking, the systems deemed to have the greatest potential impact on safety and plant performance should be given the highest priority.
2. Review the systems/components of the highest-priority systems for their design basis, materials of construction, and the service environments that exist.
    - Do environmental stressors such as weathering, presence of salt water, or a dusty environment exist?
    - Will materials impact condition? Are they suitable for the current function and environment?
    - What operational concerns exist, and is there the potential to affect multiple units or the entire facility?
    - Are there weighting factors that will affect prioritization of the systems? For example, is there the potential for spray to impact structures or activities at the facility?
    - Did construction methods create potential problems such as improper coatings or finishes, alignment concerns, or structural integrity issues?
3. Review plant and industry history regarding cooling tower failures involving similar materials, design, construction methods, and environmental conditions. Determine the probable degradation mechanisms that will be experienced (such as mechanical damage, corrosion, or weathering) and expected mean times between failures.

4. Using the above information, determine the cause and effect relationship between degradation mechanisms and the operating environment of the cooling tower to determine a probable current condition and expected likelihood of failure. Walkdowns can aid in this evaluation. For a cooling tower being inspected for a current condition issue (such as damaged or missing fill), a probability curve might look like the one shown in Figure 9-1.

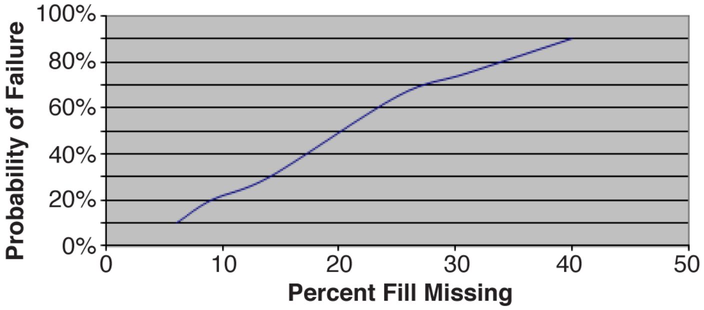

Figure 9-1
Sample probability of failure estimation for cooling tower fill

5. After determining the expected likelihood of failure of a system or a key component, determine the consequences of component failure. There can be more than one consequence of the failure of a component (for example, lost availability, compromised safety, or repair/replacement costs). In comparing the consequence of one cooling tower failure versus another cooling tower failure (or cooling tower failures versus failures on other key systems) the plant will need to have determined a unit of measure, such as lost generation.
6. Using the results of the probability and consequence analysis, create a risk grid to define the relationship between the probability of failure and the consequences of component failure. The results as depicted on the risk grid will provide guidance in prioritizing condition assessments of the systems based on expected impact to plant performance. Table 9-1 presents some sample risk relationships for cooling towers, and Figure 9-2 presents a sample risk grid based on those relationships.

Table 9-1
Sample risk relationships for cooling towers

System	Probability of Failure	Consequence (% Load Loss)
Cooling tower structure	Low	90% rated load
Fill	High	60% rated load
Cooling tower fan	Medium	10% rated load

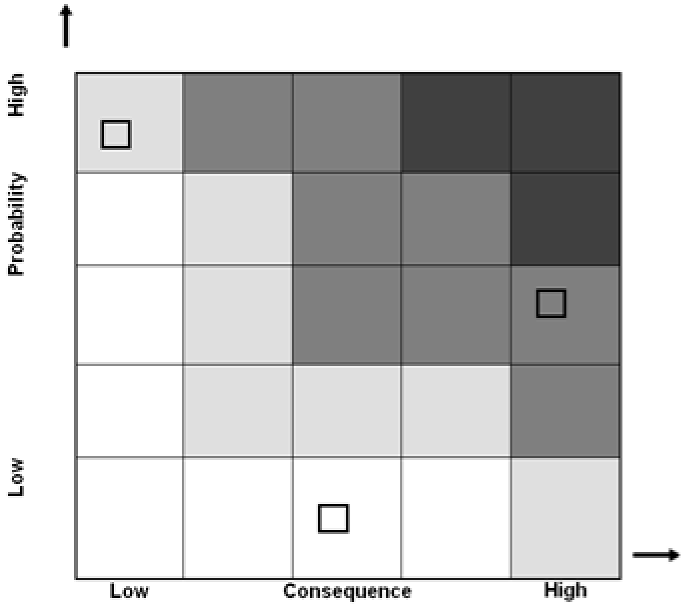

Figure 9-2
Sample risk grid for cooling towers

7. Select the assessment methodology, determine the number of inspection points, and select the inspection points. Considerations should include the following:
   - Level of perceived risk—low/high impact to the selected unit of measure.
   - Cost of inspection/assessment.
   - Extent and applicability. Do all components in a system require inspection? Will an assessment of the structure in this area provide a reasonable assessment for other structures in the same environment?
   - Availability of resources and existence of time constraints.
8. After assessment activities have been performed, update the existing risk grids to reflect current data on existing condition, expected likelihood of failure, and consequences of failure.

Section 10: Intake Structures

Overview

The circulating water system intake requires periodic inspection to ensure that restrictions are not developing so that adequate water flow to the plant is maintained and to ensure that the structure and mechanical components are in sound working order.

The intake area and the intake rack—the initial screening mechanism for stopping debris from entering the system—are inspected for accumulation of debris and sediment to ensure that flow into the cooling system is not restricted. If excessive accumulation is found, debris is removed and dredging is performed if necessary.

This section of the guideline addresses the inspection recommendations for the traveling water screens and trash rake [18]. Inspection of the structural components such as concrete or steel columns and beams is covered in Section 8.

Intake Structure Inspections

Traveling Water Screens

- Gear box – check for unusual noise or vibration
- Fluid drive – check for unusual noise or vibration
- Electric motors – check for unusual noise and vibration
- Cathodic protection – check for proper current flow
- Head shaft – inspect shaft for level, alignment of sprockets, and sprocket hubs; check sprocket tooth wear
- Carrier/tray chain – check for excessive wear
- Drive chain – check for elongation and excessive wear
- Trays and screen cloth – check for tears in cloth, missing fasteners, and frame damage
- Footshaft and boot section – check sprockets and bushings for excessive wear and clearances

- Spray nozzles – check for damage and plugging
- Hydraulic hose/piping – check for damage or leakage
- Coatings – inspect for damage to coatings and excessive corrosion

Trash Rakes

- Trolley – check for smooth movement over the full distance of travel; check for wear on trolley wheels
- Gripper – check for smooth movement over the full hoist cycle; ensure proper limit switch operation
- Wire ropes – inspect for frayed or worn condition
- Hydraulic hose/piping – check for damage or leakage
- Drive chains – check for wear or breakage; check for proper chain tension
- Electrical – inspect control panels, limit switches, hand and automatic controls, and emergency stops

The Risk-Informed Process Applied to Intake Structures

The following steps can be performed to evaluate an intake structure for prioritizing assessment activities utilizing the guidelines outlined in this report.

1. At the outset, all applicable intake structures should be reviewed by knowledgeable personnel to perform a preliminary ranking of these systems based on their criticality and expected impact on safety and plant performance. From this preliminary ranking, the systems deemed to have the greatest potential impact on safety and plant performance should be given the highest priority.
2. Review the systems/components of the highest-priority systems for their design basis, materials of construction, and the service environments that exist.
    - Do environmental stressors such as weathering or the presence of salt water exist?
    - Will materials impact condition? Are they suitable for their current function and environment?
    - What operational concerns exist, and is there the potential to affect multiple units or the entire facility?
    - Are there weighting factors that will affect prioritization of the systems, such as impact on total facility operations, or environmental concerns?
    - Did construction methods create potential problems, such as improper coatings or finishes, alignment concerns, or structural integrity issues?

3. Review plant and industry history regarding intake structure failures involving similar materials, designs, construction methods, and environmental conditions. Determine the probable degradation mechanisms that will be experienced (such as mechanical damage, corrosion, or weathering) and expected mean times between failures.
4. Using the above information, determine the cause and effect relationship between degradation mechanisms and the operating environment of the intake structure to determine a probable current condition and expected likelihood of failure. Walkdowns can aid in this evaluation. For an intake structure being inspected for current condition, a probability curve might look like the one shown in Figure 10-1.

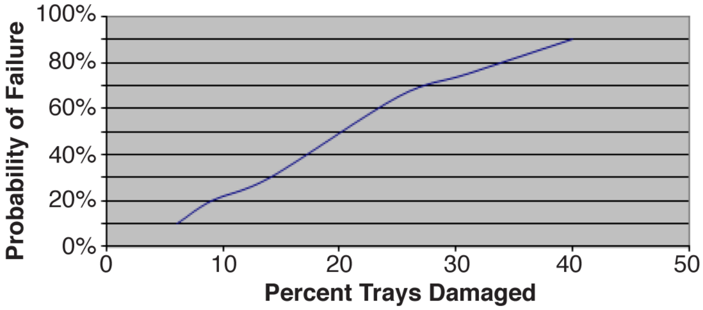

Figure 10-1
Sample probability of failure estimation for an intake structure

5. After determining the expected likelihood of failure of a system or a key component, determine the consequences of component failure. There can be more than one consequence of the failure of a component (for example, lost availability, compromised safety, or repair/replacement costs). In comparing the consequences of one intake structure failure versus another intake structure failure (or intake structure failures versus failures on other key systems) the plant will need to have determined a unit of measure, such as lost generation.
6. Using the results of the probability and consequence analysis, create a risk grid to define the relationship between the probability of failure and the consequence of component failure. The results as depicted on the risk grid will provide guidance in prioritizing condition assessments of the systems based on expected impact to plant performance. Table 10-1 presents some sample risk relationships for intake structures, and Figure 10-2 presents a sample risk grid based on those relationships.

Table 10-1
Sample risk relationships for intake structures

System	Probability of Failure	Consequence (% Load Loss)
Intake structure	Low	90% rated load
Traveling screen	Medium	40% rated load
Trash rake	High	10% rated load

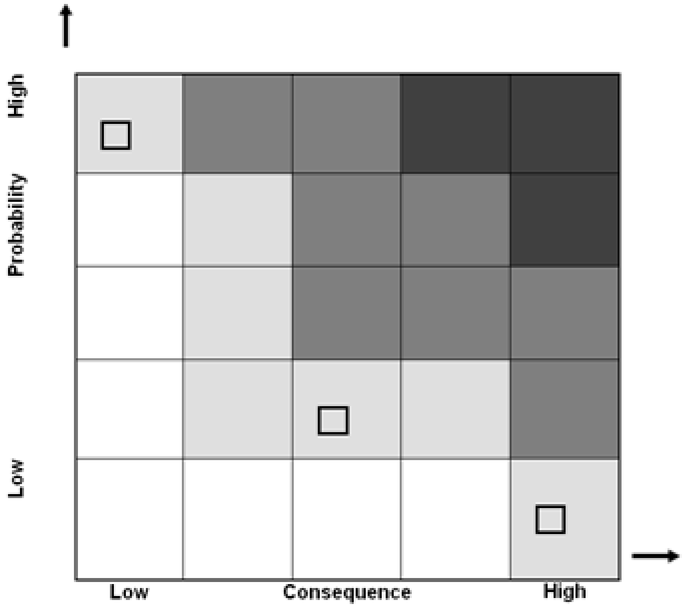

Figure 10-2
Sample risk grid for intake structures

7. Select the assessment methodology, determine the number of inspection points, and select the inspection points. Considerations should include the following:
   - Level of perceived risk—low/high impact to the selected unit of measure.
   - Cost of inspection/assessment.
   - Extent and applicability. Do all components in a system require inspection? Will an assessment of the structure in this area provide a reasonable assessment for other structures in the same environment?
   - Availability of resources and existence of time constraints.
8. After assessment activities have been performed, update the existing risk grids to reflect current data on existing condition, expected likelihood of failure, and consequences of failure.

Section 11: Railways

Overview

The rail systems at power plants can support a number of activities involving the delivery or removal of bulk material such as fuel and consumables or plant components and inventory items. It is necessary to protect rail system equipment and ensure that appropriate materials and components are installed. Because many track problems originate with faulty drainage or improper original installation, it is necessary to inspect more than just the tracks and connections themselves to ensure reliable, safe operation. It is also important to be sure that changes to the service duty of the rail system do not require upgraded components such as heavier rail.

Railway Inspections

The following are inspection guidelines for site railways [19,20]:

- Check that catch basins, gutters, ditches, pipe drains, and/or culverts are in place and functional to intercept and divert both surface water and subsurface water.
- Establish that turnouts and crossovers are properly placed and maintained.
- Check the condition of the rails for defects and ensure continuous bonding of rails. Look for the following issues:
  - Transverse fissure
  - Compound fissure
  - Horizontal split head
  - Vertical split head
  - Crushed head
  - Split web
  - Piped rail
  - Broken base
  - Square or angular break
  - Broken web
- Check for excessive gaps between rails longitudinally.
- Make sure there are no bolted joints at crossings.
- Check the track surface to ensure that it is level and that proper elevation is maintained.

- Check that the gauge of track is suitable for the load.
- Check cross ties for decay and insect damage. Replace them if decayed or mechanically worn beyond serviceability for their purpose.
- Ensure that joint bars are installed with the full number of bolts, nuts, and washers and are tightly bolted.
- Where rail anchors are used, confirm that they firmly grip the base of the rail.
- Where gauge rods are used, confirm that they are tight and in good condition.
- Ensure that the correct number of spikes are used.
- Check that all safety systems are in place and operational at street crossings and in paved areas.
- Ensure that all signs and signals are in place and are visible and legible. Electric and/or electromechanical signal inspections, circuit continuity checks, battery water level checks, trickle charger operating tests, relay point checks, and light bulb tests should conform to manufacturers' recommendations.
- Make sure that vegetation is not growing in any areas where it is not needed for erosion control. Any vegetation obstructing traffic signals and signage should be eliminated.
- Ensure that ballast is properly installed, uniform, and firmly tamped, and that it provides a good foundation.

The Risk-Informed Process Applied to Railways

The following steps can be performed to evaluate a railyard for prioritizing assessment activities utilizing the guidelines outlined in this report.

1. At the outset, all applicable railyards should be reviewed by knowledgeable personnel to perform a preliminary ranking of these systems based on their criticality and expected impact on safety and plant performance. From this preliminary ranking, the systems deemed to have the greatest potential impact on safety and plant performance should be given the highest priority.
2. Review the systems/components of the highest-priority systems for their design basis, materials of construction, and the service environments that exist.
   - Do environmental stressors such as weathering, vegetation, or temperature variations exist?
   - Will materials impact condition? Are they suitable for the current function and environment?
   - What operational concerns exist? For example, is there a need to coordinate fuel and consumable deliveries?

   - Are there weighting factors that will affect prioritization of the systems—such as impact on multiple plant systems or on the total facility's operations?
   - Did faulty construction methods such as improper weld procedures, incorrect anchoring of rails, or improper ballast tamping create potential problems?

3. Review plant and industry history regarding railway failures involving similar materials, design, construction methods, and environmental conditions. Determine the probable degradation mechanisms that will be experienced (such as mechanical damage, corrosion, or weathering) and expected mean times between failures.

4. Using the above information, determine the cause and effect relationship between degradation mechanisms and the operating environment of the railway to determine a probable current condition and expected likelihood of failure. Walkdowns can aid in this evaluation. For a railway being inspected for current condition, a probability curve might look like the one shown in Figure 11-1.

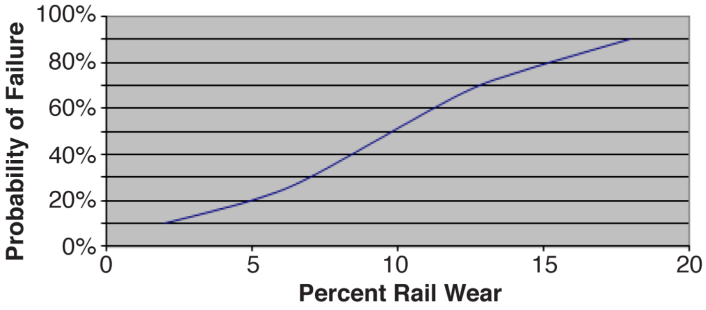

Figure 11-1
Sample probability of failure estimation for a railway

5. After determining the expected likelihood of failure of a system or a key component, determine the consequences of component failure. There can be more than one consequence of the failure of a component (for example, lost availability, compromised safety, or repair/replacement costs). In comparing the consequences of one railway failure versus another railway failure (or railway failures versus failures on other key systems) the plant will need to have determined a unit of measure, such as lost generation.

6. Using the results of the probability and consequence analysis, create a risk grid to define the relationship between the probability of failure and the consequences of component failure. The results as depicted on the risk grid will provide guidance in prioritizing condition assessments of the systems based on expected impact to plant performance. Table 11-1 presents some sample risk relationships for railways, and Figure 11-2 presents a sample risk grid based on those relationships.

Table 11-1
Sample risk relationships for railways

System	Probability of Failure	Consequence (% Load Loss)
Tracks	Medium	30% rated load
Crossties	Medium	10% rated load
Ballast	Low	10% rated load

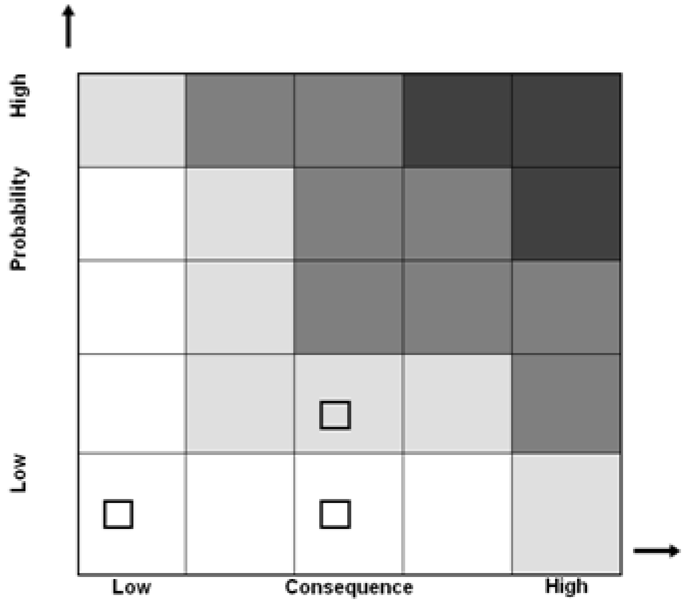

Figure 11-2
Sample risk grid for railways

7. Select the assessment methodology, determine the number of inspection points, and select the inspection points. Considerations should include the following:
   - Level of perceived risk—low/high impact to the selected unit of measure.
   - Cost of inspection/assessment.
   - Extent and applicability. Do all components in a system require inspection? Will an assessment of the infrastructure in this area provide a reasonable assessment for other infrastructure in the same environment?
   - Availability of resources and existence of time constraints.
8. After assessment activities have been performed, update the existing risk grids to reflect current data on existing condition, expected likelihood of failure, and consequences of failure.

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