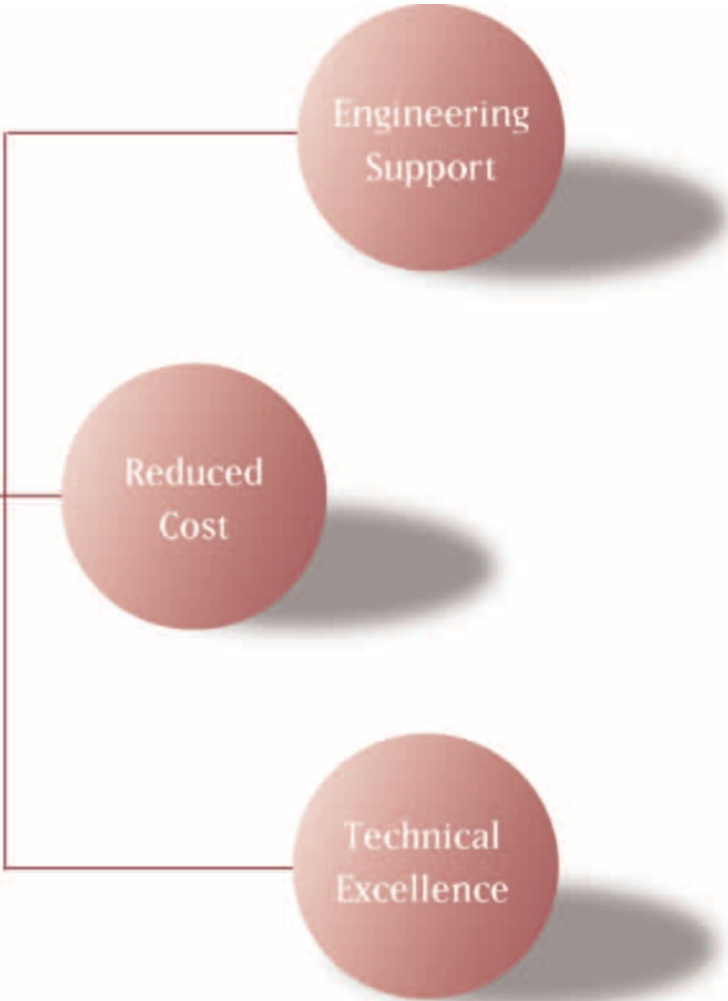


# Aging Identification and Assessment Checklist

## Mechanical Components

*Technical Report*





# **Aging Identification and Assessment Checklist**

Mechanical Components

**1009743**

Final Report, August 2004

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# PRODUCT DESCRIPTION

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Aging-related degradation continues to cause equipment reliability problems in nuclear power plants, in part because effective strategies to address aging issues are not consistently applied. Two major obstacles to forming an effective aging management strategy are a lack of understanding by plant personnel of the leading indicators of aging degradation and a lack of simple methodologies to support plant staff's application of this knowledge. This report contains component-level checklists that present likely visible indicators of aging degradation, the degradation mechanisms likely to be occurring, and the potential ramifications of such degradation. The following components are covered in this report: pumps and compressors, valves, piping and piping supports, and tanks and pressure vessels.

## Results and Findings

This report provides practical information describing the aging degradation mechanisms that may affect various plant components. The checklists detail the potential indicators of aging degradation that might be observed during a typical walkdown. In some cases, the indicators themselves may be a degraded condition that may either cause or accelerate the aging degradation mechanism.

## Challenges and Objectives

This report is intended for use by plant engineers during a walkdown of the systems and/or components for which they are responsible. Having this type of information readily available during a walkdown allows a plant engineer to:

- Identify the indicators that a component is aging
- Understand the aging degradation mechanisms that are likely to affect different plant systems, structures, and components (SSCs)
- Understand the potential impact of the degradation
- Identify conditions under which aging degradation is likely to occur

System or component engineers will be able to integrate these component-level checklists into their system walkdown procedure. In this way, many of the site-specific system monitoring requirements for license renewal and the Maintenance Rule can be addressed in a walkdown.

## Applications, Values, and Use

As nuclear plants continue to age, nuclear plant staff will need practical tools for identifying and addressing aging degradation of a particular component type. These checklists provide plant engineers with practical guidance for identifying the aging degradation based on their observations.

## **EPRI Perspective**

EPRI has created numerous products to help plant personnel meet the challenges of working with aging SSCs. This report provides this information in a form that will allow plant personnel to have a ready reference with them as they investigate the condition of plant SSCs.

## **Approach**

These checklists were developed to complement EPRI product numbers 1007932, *Identification and Detection of Aging Issues*, and 1007933, *Aging Assessment Field Guide*. The report also incorporates years of nuclear industry research and investigation into understanding and identifying aging degradation.

## **Keywords**

Aging

Aging management

Equipment reliability

Material degradation

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# 1

## INTRODUCTION

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### Background

Unanticipated equipment failures from aging-related degradation continue to negatively impact utilities' efforts to maintain equipment availability, reliability, and the maximum useful life of plant structures, systems, and components (SSCs).

Many nuclear power plants have taken or are taking the appropriate actions to renew their operating licenses for an additional 20 years. In many cases, a renewed license will allow a plant to continue operating for as much as 30 years or more from the date of renewal. The plants must continue to meet safety, production, and cost goals during that extended period. Additionally, rising prices of replacement power and environmental issues impact the cost of operation. These factors place additional focus on the need for enhanced plant reliability. Efficient management of aging effects on the plant SSCs for the remainder of plant life becomes a significant factor in maintaining plant reliability. Two major obstacles to the formation of an effective equipment aging strategy are lack of understanding by plant personnel of the leading indicators of aging degradation and a lack of simple methodologies to support plant staff's application of this knowledge.

### Related Products

In 2002, EPRI Plant Support Engineering (PSE) initiated a project to develop practical tools that enhance a plant staff's understanding of aging-related degradation of SSCs and to identify the leading indicators of the various degradation mechanisms. The tools developed from this project help plant staff to recognize degradation indicators and to take action before the degradation unacceptably reduces overall plant reliability. The tools developed from this project are intended to be complementary and to help plant personnel identify and understand the mechanisms of aging-related degradation. The following two products have also been developed from this project:

- *Identification and Detection of Aging Issues Training Material* (EPRI product number 1007932). These training materials provide a broad overview of aging management and the degradation mechanisms associated with particular material types.
- *Aging Assessment Field Guide* (EPRI product number 1007933). This pocket reference describes likely degradation mechanisms of various material types to assist plant staff in identifying both the indicators of degradation and the steps required to minimize the consequences of the degradation.

These two products address aging degradation from a materials perspective. They describe the aging degradation mechanisms likely to affect materials in plant SSCs and how to minimize the consequences of the aging degradation. The training materials are intended for engineering staff; however, they can be modified for craft personnel as well. The field guide is intended to be taken into the plant during a walkdown to reinforce or provide specific information about a topic addressed in the training materials. However, because each product contains unique information, they may be used independently of one another.

## Checklist Overview

Each appendix of this report contains the checklist for a particular component type. This report covers pumps and compressors, valves, piping and piping components, and tanks and pressure vessels. These checklists list some potential visible indicators of aging degradation, the degradation mechanisms or stressor likely to be occurring, and the potential consequences of taking no action to mitigate the degradation mechanism.

Each checklist is presented as a three-column table, with one table applicable to a particular component type. The first column lists the indicators of aging degradation likely to be observed during a walkdown. The second column lists the likely degradation mechanism occurring or the stressor that may accelerate the aging process. The last column lists the potential consequences of taking no action to mitigate the degradation (see Table 1-1).

**Table 1-1**  
**Checklist Format**

<b>Component Type</b>		
<b>Observable Indicator</b>	<b>Possible Stressor or Degradation Mechanism Producing the Indicator</b>	<b>Potential Consequence of Taking No Action</b>
Observed symptom or condition	Likely mode of degradation or condition causing the aging to be accelerated	Possible results of not acting to mitigate the degradation

## Intended Use

Checklists for individual component types can be incorporated into specific system walkdown procedures as needed; they are included here as appendices organized as follows:

- Appendix A – Checklist for Pumps and Compressors
- Appendix B – Checklist for Valves
- Appendix C – Checklist for Piping and Piping Components
- Appendix D – Checklist for Tanks, Vessels, and Accumulators

# A

## CHECKLIST FOR PUMPS AND COMPRESSORS

**Table A-1**  
**Pumps and Compressors**

<b>Observable Indicator</b>	<b>Possible Stressor or Degradation Mechanism Producing the Indicator</b>	<b>Potential Consequence of Taking No Action</b>
Excessive packing leakage or leaking seals	<ul style="list-style-type: none"><li>• Chemical or thermal degradation of nonmetallic seal materials</li><li>• Mechanical wear of seal surfaces</li><li>• Corrosion or wear of pump shaft</li><li>• Misalignment, improper packing adjustment, or damaged or degraded packing</li></ul>	<ul style="list-style-type: none"><li>• Reduced pump performance</li><li>• Drip or spray onto nearby electrical components, potentially causing electrical shorts</li><li>• Possible loss of lubrication</li><li>• Leaked fluids may damage nearby components</li><li>• Flammable liquid leakage may be a fire hazard</li><li>• Degradation of cable insulation wetted by leaked fluids</li><li>• Corrosion of nearby components</li><li>• Chemical attack of concrete pedestal</li></ul>
Loose support bolts or cracked foundation pedestal	<ul style="list-style-type: none"><li>• Change in alignment between pump, driver, and piping</li><li>• Bearing or coupling wear</li><li>• Fatigue or thermal degradation of concrete pedestal</li><li>• Change in mechanical loads with the potential for overload</li><li>• Vibration or cyclic loading</li></ul>	<ul style="list-style-type: none"><li>• Fatigue</li><li>• Increased electrical load on drive motor</li><li>• Possible loss of power transmission to pump</li><li>• Fatigue failure of pipe connections</li></ul>

**Table A-1 (Cont.)  
Pumps and Compressors**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Loose or missing equipment guards	<ul style="list-style-type: none"> <li>• Vibration or cyclic loading</li> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Personnel safety hazard</li> <li>• Equipment damage if an item comes in contact with a rotating element</li> <li>• Fatigue</li> <li>• Bearing wear</li> <li>• Coupling fatigue or wear</li> </ul>
Belts need adjustment or replacing; belt squealing	<ul style="list-style-type: none"> <li>• Increased load on belts, causing belt stretching</li> <li>• Belt slippage, causing overheating and embrittlement of drive belts</li> <li>• Possible increased drag on driven shaft</li> </ul>	<ul style="list-style-type: none"> <li>• Reduction or loss of power transmission, causing reduced pump or compressor performance</li> <li>• Overheated belts may pose a potential fire hazard</li> </ul>
Dirty or clogged filters or screens; reduced cooling water flow	<ul style="list-style-type: none"> <li>• Corrosion of upstream piping</li> <li>• Introduction of debris (including failed tank or pipe lining, corrosion products, and contaminants)</li> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Reduced suction and degraded pump performance</li> <li>• Cavitation within the pump</li> <li>• Reduced system performance</li> <li>• Pump or compressor seizing</li> </ul>
Low oil level (sight glass indication)	<ul style="list-style-type: none"> <li>• Leakage from oil system</li> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Bearing or gear wear</li> <li>• Loss of lubrication and cooling</li> <li>• Elevated temperature and thermal degradation of oil</li> </ul>

**Table A-1 (Cont.)  
Pumps and Compressors**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Reduced discharge pressure	<ul style="list-style-type: none"> <li>• Degradation of driver capability and associated speed reduction</li> <li>• Worn pump internals or bearings</li> <li>• Worn or degraded compressor or pump valves</li> <li>• Flow restriction on suction side</li> <li>• Drive belt wear</li> <li>• Possible generation of upstream debris as a result of lining failure</li> </ul>	<ul style="list-style-type: none"> <li>• Reduction in air compressor discharge pressure may jeopardize the ability of air-operated valves (AOVs) to function properly</li> <li>• Reduction in cooling water discharge pressure may limit heat removal from safety-related components</li> <li>• Reduction in fire pump discharge pressure may reduce capability of the fire protection system</li> <li>• Reduction of drive motor speed may cause degradation of motor</li> </ul>
High oil level (sight glass indication) with frothing	<ul style="list-style-type: none"> <li>• Water contamination of oil</li> </ul>	<ul style="list-style-type: none"> <li>• Oil leaks, which may create a fire hazard</li> <li>• Potential for severe metal loss on the impeller and casing</li> <li>• Reduced lubrication and cooling caused by frothing, leading to bearing failure</li> <li>• Corrosion caused by water contamination</li> <li>• Bearing or gear wear, leading to reduced performance</li> </ul>
Discolored lubricant	<ul style="list-style-type: none"> <li>• Elevated temperature exposure or excessive service period leading to thermal degradation of lubricant</li> <li>• Bearing and gear wear, creating debris</li> <li>• Contamination of the lubricant</li> </ul>	<ul style="list-style-type: none"> <li>• Bearing and gear wear</li> <li>• Contaminants in the oil may cause corrosion</li> <li>• Reduced pump or compressor performance</li> <li>• Increased load on drive motor as a result of reduced lubrication</li> </ul>
“Flowing gravel” noises	<ul style="list-style-type: none"> <li>• Cavitation within pump or in downstream connecting piping</li> </ul>	<ul style="list-style-type: none"> <li>• Potentially severe metal loss, resulting in loss of pressure boundary, impeller, or guide vanes</li> <li>• May lead to pump vibration and reduced performance</li> </ul>

**Table A-1 (Cont.)  
Pumps and Compressors**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Tapping noise	<ul style="list-style-type: none"> <li>• Vibration causing intermittent contact between loose instruments, tubing, or piping; rigid support, equipment, or structure</li> <li>• Wear of pump internals</li> <li>• Inadequately supported pipe or tubing connections</li> </ul>	<ul style="list-style-type: none"> <li>• Instrument malfunction or failure that could affect pump operation</li> <li>• Unabated vibration could lead to additional equipment damage</li> <li>• Fatigue failure of instrumentation tubing could cause a loss of control of pump operation</li> </ul>
Change in sound character	<ul style="list-style-type: none"> <li>• Increased bearing wear</li> <li>• New or increased vibration</li> <li>• New or increased cavitation</li> <li>• New air or steam leak</li> <li>• Change in pump load or operation</li> <li>• Change in drive belt condition</li> <li>• Change in flow rate</li> </ul>	<ul style="list-style-type: none"> <li>• An increase, decrease, or change in sound character can be an important indicator of changing pump or compressor performance or operating conditions</li> </ul>
Squeaking noise	<ul style="list-style-type: none"> <li>• Bearing wear</li> <li>• Wear of loose supports or piping caused by inadequately supported pipe or tubing connections</li> </ul>	<ul style="list-style-type: none"> <li>• Vibration could affect other equipment</li> <li>• Loose instrumentation may become mechanically damaged</li> </ul>
Protective coating degradation (such as discoloration, blistering, cracking, peeling, or dissolving)	<ul style="list-style-type: none"> <li>• Thermal degradation of coating caused by elevated ambient temperature or increased friction within the pump or compressor (for example, bearing wear)</li> <li>• Chemical degradation of coating</li> <li>• Mechanical damage to coating</li> <li>• Blistering caused by transmission of moisture through coating and subsequent corrosion of metal surfaces</li> </ul>	<ul style="list-style-type: none"> <li>• Loss of protective coating function will expose the metal surface to the environment, resulting in potential corrosion</li> <li>• Failed coating material could enter the system fluid flow (that is, pump lining or resurfacing material) and block the flow downstream</li> </ul>

**Table A-1 (Cont.)  
Pumps and Compressors**

<b>Observable Indicator</b>	<b>Possible Stressor or Degradation Mechanism Producing the Indicator</b>	<b>Potential Consequence of Taking No Action</b>
Corrosion product on pump surfaces	<ul style="list-style-type: none"> <li>• Corrosion of pump or compressor components, for example, uniform corrosion, pitting, and microbiologically influenced corrosion (MIC)</li> <li>• Corrosion of mounting bolts</li> </ul>	<ul style="list-style-type: none"> <li>• Unabated corrosion may result in a reduction of pump or compressor performance or a loss of pressure boundary integrity</li> <li>• Corrosion of mounting bolts may lead to vibration, pump movement, or overloaded flange joints</li> </ul>



# **B**

## **CHECKLIST FOR VALVES**

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**Table B-1  
Valves**

<b>Observable Indicator</b>	<b>Possible Stressor or Degradation Mechanism Producing the Indicator</b>	<b>Potential Consequence of Taking No Action</b>
Missing or loose hand wheels, chain wheels, or lever arms	<ul style="list-style-type: none"> <li>• Vibration, causing fasteners to loosen</li> <li>• Corrosion or wear of mating surfaces between the hand wheel and stem/shaft</li> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Inability to operate the component may prevent actions required to reduce or mitigate the effects of other problems</li> </ul>
Bent stem	<ul style="list-style-type: none"> <li>• Cyclic eccentric loading of the valve yoke</li> <li>• Overloads from the operator (that is, overthrust), misalignment on assembly, or damaged yoke</li> </ul>	<ul style="list-style-type: none"> <li>• Reduced capability of the valve to fully shut or open</li> <li>• Erratic valve operation</li> <li>• May cause excessive packing leakage</li> <li>• Increased current loads on motor or solenoid operator with potential thermal aging of the insulation material</li> <li>• Increased wear of operator components</li> <li>• Wear of valve internals</li> </ul>

**Table B-1 (Cont.)  
Valves**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Bent or cracked yoke	<ul style="list-style-type: none"> <li>• Improper torque switch setting on MOV or improper bench set and/or air pressure on AOV</li> <li>• Cyclic eccentric loading on the yoke, misalignment during assembly, improper support of the operator, or inadequate design of the yoke</li> <li>• Unplanned or excessive external force on the operator</li> </ul>	<ul style="list-style-type: none"> <li>• May reduce the valve's capability to fully shut or open or cause erratic valve operation</li> <li>• Wear of valve stem and internals</li> <li>• Increased wear of operator components</li> <li>• Increased current loads on motor or solenoid operator with potential thermal aging of insulation material</li> <li>• Fatigue failure of the yoke</li> </ul>
Corroded valve trim	<ul style="list-style-type: none"> <li>• Improperly adjusted or degraded stem packing</li> <li>• Degraded seal</li> <li>• Condensation</li> <li>• Chemical contamination from an external source</li> </ul>	<ul style="list-style-type: none"> <li>• Potential for corrosion of nearby metal components due to valve packing leakage</li> <li>• Load relaxation in bolting</li> <li>• Shaft wear</li> <li>• Corrosion of other valve components</li> </ul>
Bent, broken, or missing valve position indicator or limit switches	<ul style="list-style-type: none"> <li>• Over-ranged valve stem movement</li> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Loss of indication or improper indication may cause the valve operator to be over-ranged in the open or shut direction, affect the function of other plant safety-related equipment, or prevent valve operation</li> <li>• Loss of position indication may lead to a personnel or plant safety hazard</li> <li>• Hunting of control valves and loss of proper control and positioning</li> <li>• Fatigue of valve seat/disk</li> <li>• Fatigue of operator components</li> <li>• Increased current loads on motor or solenoid operator with potential thermal aging of insulation material</li> </ul>

**Table B-1 (Cont.)  
Valves**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Erratic or jerky stem movement	<ul style="list-style-type: none"> <li>• Wear of valve internals, stem, or operator components</li> <li>• Degradation of polymer seals within the pneumatic controller or positioner of air operator</li> <li>• Over-tightened packing</li> <li>• Wear of feedback linkage</li> <li>• Degradation of positioner components</li> </ul>	<ul style="list-style-type: none"> <li>• Can induce flow-accelerated corrosion, cavitation damage, and vibration</li> <li>• Can affect the safety-related function of other associated equipment or components</li> <li>• May affect the valve's ability to perform its function</li> <li>• May reduce the valve's capability to fully open or shut</li> </ul>
Lubricant leaking from valve operator	<ul style="list-style-type: none"> <li>• Degradation of polymer seals in operator</li> <li>• Wear of operator components</li> </ul>	<ul style="list-style-type: none"> <li>• Loss of lubricant may cause wear, resulting in erratic or impeded valve operation</li> <li>• Leaked lubricant may degrade nearby polymers (for example, cable insulation or exposed nonmetallic instrumentation components) upon contact</li> </ul>
Safety wire seal broken on relief valve	<ul style="list-style-type: none"> <li>• Corrosion of seal wire</li> <li>• Mechanically broken seal wire</li> <li>• Fatigue due to vibration</li> <li>• Valve set point was intentionally changed</li> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Inadvertent change of the set point may cause under- or over-pressurization of the system</li> </ul>
Solenoid operator hotter than normal to touch	<ul style="list-style-type: none"> <li>• Development of short or open circuits within the windings</li> <li>• Corrosion of leads or coil terminations</li> <li>• A change in the valve service requirements (for example, duration of the energized state) or a change in the ambient environment</li> <li>• Change in control fluid temperature or condition</li> </ul>	<ul style="list-style-type: none"> <li>• Shorted or open winding circuits may prevent the solenoid from repositioning the valve</li> <li>• Thermal aging of the solenoid insulation</li> <li>• Degraded performance or failure of the solenoid operator</li> </ul>

**Table B-1 (Cont.)  
Valves**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Hissing sound (air leak)	<ul style="list-style-type: none"> <li>• Chemical degradation or thermal aging of the diaphragm</li> <li>• Mechanical damage or wear of the diaphragm or seals</li> <li>• Fatigue failure of tubing or diaphragm</li> <li>• Mechanical damage of tubing connections</li> <li>• Possible inappropriate maintenance practices (for example, painting the edges of the diaphragms)</li> </ul>	<ul style="list-style-type: none"> <li>• Loss of pressure may cause spontaneous, erratic, or impeded valve operation</li> <li>• Hunting and loss of proper positioning</li> </ul>
Excessive air operator piston blow-by	<ul style="list-style-type: none"> <li>• Aging and/or mechanical degradation of polymer seals</li> <li>• Galling between operator moving internal surfaces</li> </ul>	<ul style="list-style-type: none"> <li>• By-passing the operator piston can cause the component to respond slowly or erratically to a control signal</li> <li>• Hunting and loss of proper positioning</li> </ul>
Warm discharge piping from steam safety/relief valve	<ul style="list-style-type: none"> <li>• Wire drawing of the valve seat</li> <li>• Deformation or mechanical damage to the polymer seat</li> <li>• Corrosion of valve internals</li> <li>• Entrapped debris (for example, corrosion products)</li> </ul>	<ul style="list-style-type: none"> <li>• Loss of system fluids</li> <li>• Undue burden on waste fluid collection/treatment system</li> <li>• Shift in lift and/or reset points</li> </ul>
Protective coating degradation (such as discoloration, blistering, cracking, peeling, or dissolving)	<ul style="list-style-type: none"> <li>• Thermal degradation of the coating</li> <li>• Chemical degradation of the coating</li> <li>• Mechanical damage to the coating</li> <li>• Blistering caused by the transmission of moisture through the coating and subsequent corrosion of the metal surface</li> <li>• Peeling as a result of improper surface preparation or application</li> </ul>	<ul style="list-style-type: none"> <li>• Loss of protective coating function will expose the metal surface to the environment, potentially resulting in corrosion</li> <li>• Failed coating material can enter the system fluid flow, blocking the flow downstream</li> </ul>

**Table B-1 (Cont.)  
Valves**

<b>Observable Indicator</b>	<b>Possible Stressor or Degradation Mechanism Producing the Indicator</b>	<b>Potential Consequence of Taking No Action</b>
<ul style="list-style-type: none"><li>Leaking flange joints or packing</li></ul>	<ul style="list-style-type: none"><li>Wire drawing or erosion of the flange face</li><li>Bolt fatigue</li><li>Relaxation of the bolt clamping force</li><li>Possible inappropriate maintenance practices</li></ul>	<ul style="list-style-type: none"><li>Corrosion of nearby equipment</li><li>Loss of pressure boundary integrity</li><li>Plant and personnel safety hazard</li><li>Loss of system fluid</li><li>Corrosion of the flange face and flange bolts</li><li>Corrosion of the valve trim and bonnet bolts</li></ul>



# C

## CHECKLIST FOR PIPING AND PIPING SUPPORTS

**Table C-1**  
**Piping and Piping Supports**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Corrosion stains seeping through thermal insulation or wetted thermal insulation	<ul style="list-style-type: none"> <li>• Corrosion of pipe wall external surface due to wetted insulation</li> <li>• Internal corrosion, erosion, or flow-accelerated corrosion (FAC) that produced a pinhole leak</li> <li>• Leakage from a flange or valve packing, causing wetted thermal insulation</li> </ul>	<ul style="list-style-type: none"> <li>• Eventual loss of pressure boundary</li> <li>• Corrosion of nearby metal surfaces as water drains/drips from the wetted insulation</li> <li>• Spillage or leakage from an external source may cause degradation of a nearby system or structure</li> </ul>
Damaged or missing thermal insulation	<ul style="list-style-type: none"> <li>• Mechanical impact</li> <li>• Water hammer event</li> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Potential thermal hazard to personnel</li> <li>• Dynamic event (such as impact or water hammer) resulting from damaged or removed insulation may have caused unseen damage to the pipe, supports, or connected equipment</li> <li>• Corrosion of the pipe wall where insulation degradation results from wetting</li> </ul>

**Table C-1 (Cont.)  
Piping and Piping Supports**

<b>Observable Indicator</b>	<b>Possible Stressor or Degradation Mechanism Producing the Indicator</b>	<b>Potential Consequence of Taking No Action</b>
Leaks at threaded connections	<ul style="list-style-type: none"> <li>• Corrosion of threaded members</li> <li>• Degradation or loss of thread sealant</li> <li>• Mechanical damage to threads or seating surface</li> <li>• Vibration or fatigue</li> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Poses wetting and/or corrosion damage potential to the surrounding equipment</li> <li>• May lead to joint rupture and a loss of system/component function</li> </ul>
Flange nuts, studs, or bolts that are missing or not fully engaged	<ul style="list-style-type: none"> <li>• Vibration or fatigue</li> <li>• Improper assembly</li> <li>• Possible inappropriate maintenance practices</li> <li>• Relaxation of bolt clamping force</li> </ul>	<ul style="list-style-type: none"> <li>• Corrosion of the pipe flange and flange bolting</li> <li>• Corrosion of the pipe outside diameter (OD) under insulation</li> <li>• Corrosion of the surrounding equipment</li> <li>• Loss of the pressure boundary</li> <li>• Less than the intended design clamping load may lead to leakage or unwanted pipe movement during a pressure transient or water hammer event</li> </ul>
Temporary shielding suspended from pipe	<ul style="list-style-type: none"> <li>• Inappropriate shielding practices and reduced awareness of their impact on equipment and plant safety</li> </ul>	<ul style="list-style-type: none"> <li>• Deformation of pipe</li> <li>• Increased stress levels in flange or connection bolting</li> <li>• Increased stress levels in pipe supports and anchor bolts</li> </ul>
Excessive sweating or condensation collecting on pipes	<ul style="list-style-type: none"> <li>• Nearby hot water or steam leak</li> <li>• Change in either system operating temperature or local environment (for example, higher humidity)</li> <li>• Degraded or missing anti-sweat insulation</li> </ul>	<ul style="list-style-type: none"> <li>• High humidity may affect operation of equipment or instrumentation in the area</li> <li>• Corrosion of wetted pipe</li> <li>• Corrosion of nearby equipment</li> <li>• Wetting of surrounding electrical components, leading to potential electrical failure</li> </ul>

**Table C-1 (Cont.)  
Piping and Piping Supports**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Deformed or cracked polymer piping	<ul style="list-style-type: none"> <li>• Thermal (hot or cold) degradation of pipe</li> <li>• Chemical attack of pipe (for example, spillage from an external source)</li> <li>• Radiation-induced degradation of pipe</li> <li>• Mechanical damage caused by over-pressurization (for example, abnormal operating pressure or water hammer transient)</li> </ul>	<ul style="list-style-type: none"> <li>• Degradation of pipe structural properties may lead to leakage or pipe rupture</li> </ul>
Cracked or deformed elastomeric expansion joints	<ul style="list-style-type: none"> <li>• Thermal (hot or cold) degradation of expansion joint</li> <li>• Chemical attack (for example, spillage from an external source)</li> <li>• Radiation-induced degradation of expansion joint</li> <li>• Mechanical damage caused by over-pressurization</li> <li>• Mechanical damage caused by over-ranging joint movement</li> </ul>	<ul style="list-style-type: none"> <li>• Degradation and loss of expansion joint structural properties may result in rupture</li> <li>• Over-ranging may be indicative of excessive pipe movement and potential degradation of pipe supports</li> </ul>
Vibration	<ul style="list-style-type: none"> <li>• Degradation of pipe supports</li> <li>• Vibration may be caused by flow conditions or equipment operation</li> </ul>	<ul style="list-style-type: none"> <li>• Vibration may affect instrumentation performance and output</li> <li>• Fatigue of pipe joints or welds</li> <li>• Wear of pipe wall at metal-to-metal rubbing</li> <li>• Increased stress loading at connections to equipment</li> </ul>

**Table C-1 (Cont.)  
Piping and Piping Supports**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Pipe out of normal location	<ul style="list-style-type: none"> <li>• Pipe movement may be indicative of previous water hammer event</li> <li>• Pipe movement may be caused by thermal changes</li> </ul>	<ul style="list-style-type: none"> <li>• May affect operation of connected equipment (for example, stress imposed on the pump may be translated to coupling, causing misalignment and wear)</li> <li>• Increased stress loading at flange joints and connections to equipment</li> <li>• Increased stress loading of pipe supports and anchor bolting</li> </ul>
“Flowing gravel,” “tumbling rocks,” or “tumbling boulder” noises	<ul style="list-style-type: none"> <li>• Cavitation</li> </ul>	<ul style="list-style-type: none"> <li>• Metal loss from the pressure boundary with eventual penetration and leakage</li> </ul>
Hissing sound coming from piping	<ul style="list-style-type: none"> <li>• Fatigue failure of pipe joints</li> <li>• Corrosion of pipe wall, causing leak</li> <li>• Mechanical damage of tubing connections</li> <li>• Degradation of flange joint gasket or bolting</li> <li>• Incipient cavitation</li> </ul>	<ul style="list-style-type: none"> <li>• Air or steam leakage</li> <li>• Reduction or loss of function of air-operated equipment</li> <li>• Wetting of pipe insulation or surrounding equipment</li> <li>• Increased humidity can affect operation of equipment or instrumentation in the area</li> </ul>
Pipe unexpectedly warm or hot to touch	<ul style="list-style-type: none"> <li>• Corrosion or erosion of valve seat or disk</li> <li>• Reduced heat transfer across heat exchanger tubes</li> <li>• Mechanical failure of valve operating mechanism</li> <li>• Corrosion of check valve, causing it to remain open</li> <li>• Loss of control air or electrical power to valve operator, allowing valve to remain open</li> </ul>	<ul style="list-style-type: none"> <li>• Lifting relief valve can require additional makeup and may restrict the system’s ability to maintain adequate pressure</li> <li>• Valve leakage can cause undue burden on wastewater treatment system</li> <li>• Unplanned flow or pressure in piping may pose personnel safety hazard</li> </ul>

**Table C-1 (Cont.)  
Piping and Piping Supports**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Tape residue on pipe	<ul style="list-style-type: none"> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Stress corrosion cracking can lead to catastrophic loss of pressure boundary integrity</li> <li>• Stress corrosion cracking of austenitic stainless steels or nickel-based alloys</li> <li>• Liquid metal embrittlement</li> </ul>
White crystalline residue on pipe	<ul style="list-style-type: none"> <li>• Degradation of valve packing or flange joint integrity</li> <li>• Boric acid spillage or leakage from a joint or valve in the pipe or from an external source, such as an overhead component</li> </ul>	<ul style="list-style-type: none"> <li>• Leakage from primary coolant systems may cause increased radioactivity levels in the area</li> <li>• Boric acid corrosion of pipe or surrounding equipment</li> </ul>
Plastic tie wraps supporting pipe	<ul style="list-style-type: none"> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Inadequate support that can allow excessive pipe movement during normal operation</li> <li>• Fatigue of piping connections</li> <li>• Loss of pipe support during dynamic event</li> <li>• Vibration and wear</li> </ul>
Corroded pipe support or hanger	<ul style="list-style-type: none"> <li>• Leakage from the pipe or from an external source wetting the support surfaces</li> <li>• Failed protective coatings</li> <li>• Chemical attack</li> </ul>	<ul style="list-style-type: none"> <li>• Degraded support may allow pipe movement and vibration</li> <li>• Reduced support capacity</li> </ul>
Deformed, misaligned, or detached pipe support or hanger	<ul style="list-style-type: none"> <li>• Water hammer event</li> <li>• Corrosion, leading to reduced capability and bending/breaking</li> <li>• Vibration</li> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Degraded support may allow pipe movement and vibration</li> <li>• Reduced support capacity</li> <li>• Wear of pipe wall when deformation loosens pipe support</li> <li>• Potential fatigue when loose support allows pipe movement</li> </ul>

**Table C-1 (Cont.)  
Piping and Piping Supports**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Spring hanger "bottomed out"	<ul style="list-style-type: none"> <li>• Increased stress loading on pipe welds and joints</li> <li>• Pipe relocation caused by water hammer or change in thermal growth of pipe</li> <li>• Broken spring in hanger</li> </ul>	<ul style="list-style-type: none"> <li>• Potentially significant increase in loads on hanger</li> <li>• Inadequate support during pressure transient events</li> </ul>
Bent pipe hanger rod	<ul style="list-style-type: none"> <li>• Increased stress loading on pipe welds and joints caused by pipe relocation</li> <li>• Previous dynamic event, such as a water hammer</li> </ul>	<ul style="list-style-type: none"> <li>• Potential change in pipe slope may affect system operation, internal corrosion of pipe, or future likelihood of a water hammer</li> <li>• Inadequate support during pressure transient events</li> </ul>
Nut missing from U-bolt clamp	<ul style="list-style-type: none"> <li>• Vibration</li> <li>• Possible inappropriate maintenance practices</li> </ul>	<ul style="list-style-type: none"> <li>• Inadequate support may allow excessive pipe movement during normal operation</li> <li>• Reduced support capacity</li> <li>• Fatigue of pipe welds and joints</li> <li>• Wear of pipe wall at support</li> </ul>
Two adjacent pipes in contact with one another	<ul style="list-style-type: none"> <li>• Pipe relocation as a result of a previous dynamic event, such as a water hammer</li> <li>• Change in thermal growth of the pipe</li> <li>• Degradation or failure of one or more pipe supports</li> </ul>	<ul style="list-style-type: none"> <li>• Continued wear may affect pressure boundary integrity</li> <li>• Wear of pipe walls at contact points</li> <li>• Deformation or overload of pipe support</li> <li>• Increased stress loading on pipe welds and joints caused by pipe relocation</li> </ul>
Protective coating degradation (such as discoloration, blistering, cracking, peeling, or dissolving)	<ul style="list-style-type: none"> <li>• Thermal degradation of coating</li> <li>• Chemical degradation of coating</li> <li>• Mechanical damage to coating</li> <li>• Blistering caused by transmission of moisture through coating and subsequent corrosion of metal surface</li> </ul>	<ul style="list-style-type: none"> <li>• Discolored coating may be indicative of thermal or chemical degradation of the coating</li> <li>• Loss of protective coating function will expose the metal surface to the environment, potentially resulting in corrosion</li> </ul>

# D

## CHECKLIST FOR TANKS, VESSELS, AND ACCUMULATORS

**Table D-1**  
**Tanks, Vessels, and Accumulators**

<b>Observable Indicator</b>	<b>Possible Stressor or Degradation Mechanism Producing the Indicator</b>	<b>Potential Consequence of Taking No Action</b>
Protective coating degradation (such as discoloration, blistering, cracking, peeling, or dissolving)	<ul style="list-style-type: none"><li>• Thermal degradation of coating</li><li>• Chemical degradation of coating</li><li>• Mechanical damage to coating</li><li>• Blistering caused by moisture transmission through coating and subsequent corrosion of metal surface</li></ul>	<ul style="list-style-type: none"><li>• Discolored coating may be indicative of thermal (for example, defective heat tracing) or chemical (for example, chemical spill) degradation of the coating</li><li>• Loss of protective coating function will expose the metal surface to the environment, potentially resulting in corrosion</li></ul>
Dirt on top of tank ring wall	<ul style="list-style-type: none"><li>• Possible inappropriate maintenance practices</li><li>• Nearby excavation/construction activities that changed the landscape and grade level</li></ul>	<ul style="list-style-type: none"><li>• Corrosion of tank wall</li><li>• Corrosion of anchor bolts</li><li>• Loss of anchor bolts may allow tank movement</li><li>• Unabated corrosion may cause loss of fluid boundary integrity</li></ul>
Corrosion product on exterior of tank wall	<ul style="list-style-type: none"><li>• Uniform corrosion of tank wall</li><li>• Localized corrosion of tank wall seam welds</li><li>• Failed protective coatings</li></ul>	<ul style="list-style-type: none"><li>• Unabated corrosion may cause loss of fluid boundary integrity</li></ul>

**Table D-1 (Cont.)  
Tanks, Vessels, Accumulators**

Observable Indicator	Possible Stressor or Degradation Mechanism Producing the Indicator	Potential Consequence of Taking No Action
Corrosion product on manway bolting	<ul style="list-style-type: none"> <li>• Corrosion of bolts</li> <li>• Corrosion of manway or tank wall</li> <li>• Manway gasket degradation and leakage</li> </ul>	<ul style="list-style-type: none"> <li>• Loss of manway bolt capacity may cause loss of structural integrity</li> </ul>
Banging sound in steam heat piping	<ul style="list-style-type: none"> <li>• Possible water hammer imposing cyclic load on piping and piping connections to tank</li> </ul>	<ul style="list-style-type: none"> <li>• Vibration can cause flange joint leakage</li> <li>• Potential fatigue fracture and loss of pipe or tank structural integrity</li> <li>• Fatigue of pipe welds, joints, and connections to tank</li> </ul>
Vibration of pipe connected to tank	<ul style="list-style-type: none"> <li>• Inadequately supported pipe</li> <li>• Cyclic pressure transients within the pipe</li> </ul>	<ul style="list-style-type: none"> <li>• Vibration can cause flange joint leakage</li> <li>• Potential fatigue fracture and loss of pipe or tank structural integrity</li> <li>• Increased cyclic stress loading of pipe connection to tank wall</li> <li>• Fatigue</li> </ul>
Reduced or lost accumulator pre-charge pressure	<ul style="list-style-type: none"> <li>• Degradation of bladder</li> <li>• Degradation of piston seals</li> <li>• Degradation of gas valve, leading to leakage</li> <li>• Change in system fluid pressures or conditions</li> </ul>	<ul style="list-style-type: none"> <li>• Reduced system pressure may affect pump performance</li> <li>• Reduced system pressure may result in cavitation and inadequate net positive suction head (NSPH)</li> <li>• Reduced system pressure may allow unplanned phase change in high-temperature regions of heat exchangers</li> </ul>

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