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INTRODUCTION

All physical systems and process equipment undergo continuous change as a result of their chemical exposure, natural environment, service conditions, electromagnetic fields and gravity just to mention a few. When systems change, their physical properties and performance characteristics are often altered. Usually this alteration is one of deterioration or worsening. When there is a mismatch between assumed design properties and actual properties, system integrity may be compromised and failure may be more likely. The lifecycle of existing industrial facilities has increased over the past few decades. Many facilities are now operating beyond their intended life span and at somewhat harsher or more aggressive conditions. Consequently, aging may be more prevalent under more severe operating conditions, harsh weather extremes and an increase in the number of upsets, start-ups and outages than may have been originally planned or designed.

We generally measure age in increments of time. In fact, from a scientific perspective, time is simply a measure of change. Time can be measured in years or decades, or in the number of operating hours. Some forms of aging (e.g., metal fatigue) are measured in terms of the number of unit operating cycles a structure is subjected to. We often associate aging with deterioration. As we grow older our bodies deteriorate and we are often unable to undertake activities we enjoyed in earlier times. Physical structures and process equipment also have a tendency to deteriorate with age. In some venues aging is not necessarily viewed as negative; vintage wines often improve with age. From an aesthetic perspective society tends to value older architecture as well as ancient ruins and artifacts. However, this is not the case for Industrial facilities.

As systems age chronologically, three outcomes are possible:

1. Properties may improve
2. No change may take place
3. Properties may deteriorate

While the first two of the listed outcomes are not typical for process and infrastructure facilities and are not addressed in the book, the third represents a risk to a safe and reliable operation in the process industries.

1.1 OVERVIEW

Aging equipment presents a challenge to managing the integrity of plants and associated infrastructure. Included in this scope are chemical plants, oil refineries, power plants (including nuclear), steel mills, manufacturing plants, pipeline terminals and railways to mention just a few. Rigorous in-house methods must be employed to gauge quality and reliability at a given point in time. Second, and most important, the aging process and associated deterioration is not necessarily linear with time, making strategic decisions somewhat difficult.

As indicated, the aging process in physical systems and equipment is one associated with deteriorating properties and conditions. However, equipment aging does not necessarily correlate with chronological age or time in service. Aging does not necessarily equate to visible wear and tear, either. Given that time is not the only factor in the aging process, aging can simply be considered as negative or undesirable change that can result in diminished integrity and reliability. There are many ways in which material may react with its environment. Changes may affect the physical as well as chemical properties of the material including but not limited to the thickness, the crystalline structure, the tensile strength, the conductivity, and the ductility. Everyone associated with the operation and management of chemical facilities shares the challenge to operate facilities safely and reliably. To do so, it may require not only timely intervention to fix problems when they occur, but periodic inspections and system testing throughout the entire lifecycle of equipment change.

1.2 PURPOSE

This book is about the aging of process facilities and infrastructure. It explores some of the many ways that equipment in the process industries might age and suggests some of the warning signs for which to look. It is primarily intended to provide helpful ideas and suggestions to persons on the front line charged with the responsibility for dealing with aging equipment. The scope herein not only includes equipment in direct contact with process fluids or exposed to operating conditions but, additionally, the infrastructure that supports the operation. Included in this category are roads, buildings, support structures (pipe racks and access platforms), sewers, power lines, pipelines, tanks, silos, loading racks, marine facilities, and waste water/sewage ponds. Electrical equipment and instrumentation are also subject to physical aging as well as redundancy. This category includes conduits, cable trays, transformers and switchgear.

This book highlights a growing concern in the process industries. It is intended to enlighten the reader on some of the current issues confronting the safe operation and management of industrial facilities. It does not provide prescriptive advice for dealing with aging but suggests some ideas that might be applied as part of an Asset Management program. Many of these ideas have been tried and tested by CCPS member companies. Ultimately, some difficult decisions will need to be made to determine what equipment to replace and what equipment may continue to be operated safely. By recognizing and understanding aging it is hoped one can adopt strategies to help operate facilities in a safe and responsible manner.

Some examples of aging facilities are shown in Figures 1.1-1 and 1.1-2. While the effect of passage of time on this equipment is recognizable from external appearances, this is not always the case. Visual appearance alone is not sufficient to gage the condition of an asset.

1.3 AGING: CONCERNS, CAUSE AND CONSEQUENCES

What is it about aging equipment that should be of concern? It is the unknown and increased potential for failure, resulting in safety, environmental incidents or business interruption. Such failure may be physical or functional. Either category can have catastrophic consequences. An example of physical failure is material breakage due to pre-existing high stresses or deteriorated properties. A functional failure is one that impedes or interferes with the intended functional capacity of a system. Instrumentation and control systems are susceptible to functional failure due to aging.

Physical failures are often visible to the naked eye and there may be warning signs prior to major consequences. Sometimes physical integrity may be difficult to detect or measure through visible means. Hidden defects can contribute to a future failure. Likewise, functional failures are often less obvious and may be more difficult to detect. A physical failure can coincide with a functional failure if a system is unable to perform its required function following failure. An example of a physical failure without functional consequence might be paint peeling or deteriorating on a metal surface while the properties and performance of the metal component are not immediately affected.

Figure 1.1-1. Image of an Aging Facility Containing Silos

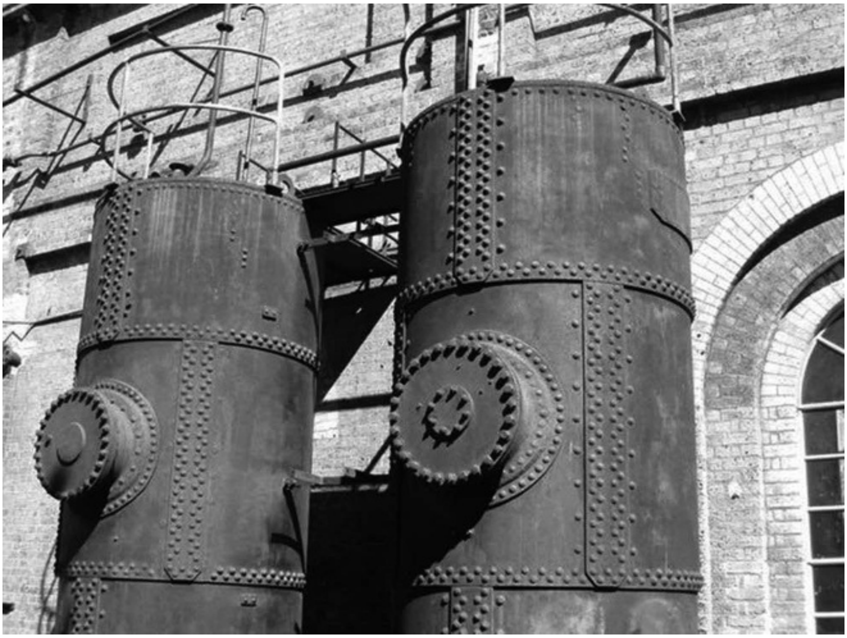

Figure 1.1-2. Vintage Vessels Fastened with Rivets

On the other hand, a purely functional failure might be the inability of equipment to operate at high (previously demonstrated) throughput. A system that does not perform properly when required to do so can undermine the safety and integrity of an operation. Electrical and instrumentation systems fall into this category. We depend on high availability under all situations.

Physical failure can occur in systems and equipment being exposed to forces whether they are mechanical, electrical or magnetic. The actions of chemical (both environmental and process chemicals) exposure can also contribute to physical failures. For instance, Stress Corrosion Cracking (SCC) issues on pipelines are both environmental and mechanical physical failures (stress related and time dependent).

The simplest of these forces is gravity. Gravity exerts a downward force on all equipment and upon prolonged exposure it can cause bending or sagging. If moving parts are involved, shaft alignment may become distorted causing increased wear from friction.

Structural creep is a phenomenon related to gravity whereby slight dimensional changes take place upon prolonged exposure to high loads. Structural creep is irreversible. Creep in metals occurs at a higher temperature and causes minute, incipient grain boundary melting or micro voids that cause weakening. Creep often occurs in boiler and process heater tubes (e.g., ethylene cracking furnaces). Sometimes creep is accompanied by surface or concealed cracking which may progress towards a mechanical failure. Creep may also occur at normal environmental temperatures resulting in sagging. An extended structural member or long span of piping is subject to normal gravity as well as operating loads and weather (snow and ice). Over time such components may bend or sag in response to these forces. Whether the strength of the affected components is impaired may require careful inspection and analysis.

Electric and electromagnetic forces are present in all operating equipment and structures. Electric and electromagnetic forces can alter the grain structure of steel leading to local weak spots creating the potential for failure.

Physical materials are typically chosen because of their tensile strength as well as their chemical properties. Ferrous metals are commonly employed in the process industries for vessels, piping and other equipment. Metal must be rigid and strong enough to withstand forces in an operating environment. Properties such as thermal or electrical conductivity, hardness, resistance to chemicals are some of the prerequisites to material selection. Process equipment materials may also include glass, rubber, ceramic and other metals including alloys. When the important properties of process equipment are diminished or compromised, such equipment may no longer be fit for service and a failure may be more likely to occur. Failures related to equipment aging will be dealt with in more detail in subsequent chapters.

Chemical exposure is another contributor to equipment aging. All equipment is exposed to chemical substances which constitute the operating environment. That environment may include air, steam, water, corrosive liquids and vapors, reactive chemicals, organic compounds and biomatter. Various forms of residue may accumulate in equipment and, if not properly cleaned for several years, can contribute to material degradation and plugging. This material may be difficult to remove if service conditions have changed and it has become integrated with the base metal.

The most common category of chemical change is corrosion. When two or more incompatible materials come into contact, chemical change is inevitable. Chemical change affects not only the exposed surface of equipment but it may penetrate far into the material thickness compromising the physical properties for which the material was selected. System incompatibility may result due to hybrid systems comprised of old and new components. Some incompatibility may exist contributing to confusion and human error, adjustment of dimensional discrepancies using improper materials, galvanic corrosion and electromagnetic currents (e.g., at underground and above ground piping transitions).

Many of these mechanisms may be involved in service aging. Service aging is the product of the operating history of the equipment, including failures, breakdowns and process upsets and how these operating conditions have impacted the remaining life of the equipment. This is particularly true when the equipment was originally designed based on known/expected damage mechanisms and failure modes as determined by a process hazard analysis, but during its operating life those original design conditions have changed, resulting in increased deterioration and the potential for breakdown.

Natural events can also affect equipment and structural aging. As equipment gets older it has a higher probability of being exposed to "rare" events which may not have been thought of in the design. Flooding allows ingress of water and moisture into structures with deleterious impact, or subjects vessel supports to upwards stress due to buoyancy. Drought can cause changes in the water table and impartment of equipment ground systems. Natural settling causes foundation sinking or distortion that weakens support structures. Extreme wind can exceed wind loads or cause surface erosion from blowing sand and dust. Soil creep, expansive soils, and seismic activity may produce long term cumulative effects.

Lack of documentation and knowledge is also a concern associated with aging equipment. Record keeping on older facilities was not always to the level of detail as required by current safety regulations. A written history of service conditions or upsets during the entire lifecycle often does not exist, and tenured staff with this information may have left or retired. Often older facilities have had several owners, and equipment records have been lost or misplaced. Third party leased equipment and facilities may also present these problems: unknown design basis and materials of construction, unknown history, unknown previous service, liabilities, etc.

1.4 HOW AGING OCCURS

Aging is about change and it is driven by exposure conditions and forces. Aging may involve changes in physical dimensions and appearance or it may involve changes in properties. Even if those conditions or exposures are constant, there is no guarantee that aging will progress in a linear fashion. Visual changes such as discoloration, cracking, peeling paint and other surface blemishes are often cosmetic in nature and are unlikely to pose a risk of failure. They are still indicative of change however and should trigger a more in-depth look at properties to determine if these have been altered.

Aging is commonly associated with the progression of time within the lifecycle of a system or facility. From a reliability and integrity perspective, however, aging also recognizes that physical and chemical properties may deteriorate upon continuous or intermittent exposure to normal or upset operating conditions. The fact is, even exposure to a stable or dormant environment can bring about deterioration in some systems. Such deterioration, if not detected and addressed, can make systems more prone to failure. The goal is to aim for better understanding of the process of aging so that better informed decisions can be made, and catastrophic events avoided. Figure 1.4-1 depicts an aging scale which illustrates how aging evolves from minor cosmetic defects to total destruction.

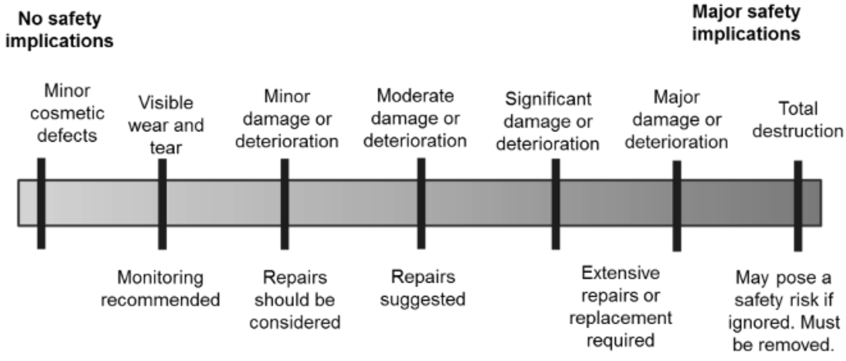

Figure 1.4-1. Suggested Spectrum for Aging Facilities

1.4.1 Metallic Corrosion

Metallic corrosion and surface deterioration are likely the most visible symptoms of aging and are familiar to all of us. Most metals including alloys react with their environment. The rate at which this occurs is a function of the base metal properties, other materials or contaminants at the point of exposure and conditions such as temperature. For simple rust to occur, air and moisture must be present. If the surface contaminants are in the low pH range, corrosion will occur at a more rapid rate. A layer of rust, if left undisturbed, can actually provide a protective layer to prevent further corrosion of some ferrous metals. Operating parameters such as fluid velocity can influence the removal of corrosion products thereby exposing base metal and further aggravating the problem. What's interesting about corrosion is that, once it begins it is difficult to stop it even if the exposure is controlled. Removal of surface deposits down to base metal is often required but this causes harm since it reduces the metal thickness. Unless surface protection such as paint is applied and efforts are made to control the exposure, further deterioration can occur. It is also important to mention that episodic corrosion due to exposure from an accidental release of a corrosive material (such as acid) can also take place, and may damage the surface of the infrastructure. Having proper spill prevention programs in place may prevent infrastructure deterioration caused by releases of corrosive. Also, corrosion products which are toxic or pyrophoric may be classified as hazardous waste and may require regulated disposal procedures.

While rust is a common form of corrosion found on the surface of ferrous metals, there are many other related corrosion mechanisms that can also hinder the properties of various metals. These include pitting, fretting, stress-corrosion cracking, galvanic corrosion, hydrogen attack and sulfidation. Each mechanism has its own symptoms and causes, and a thorough knowledge of metallurgy is required to ensure that systems are designed to match all anticipated operating conditions. In the past, some facilities may have been designed and built without the benefit of such knowledge. Furthermore, as operating conditions evolved over later years, a mismatch between design and operation may have occurred without being recognized.

The effects of metal corrosion are more than just a reduction in material thickness. Corrosion can alter the physical properties of metal. Ductility, hardness, porosity and electrical conductivity are just a few of these. A corroded or tarnished surface of an electrical contact point can act as an insulator and may contribute to a power interruption. Electrical fixtures and instrument boxes contain thousands of metal contacts which are subject to aging and deterioration. These can suddenly fail to conduct current without prior warning. They must be opened and inspected at regular intervals.

There are many different types of corrosion and the causal mechanisms vary widely. It is difficult, if not impossible, to find a metal or alloy that is not vulnerable to some type of corrosion. Prudent material selection during the design phase provides the best opportunity to combat the problem. It is beyond the scope of this book to examine all the various types of corrosion and their effects on metal properties. However, one fact is noteworthy. Corrosion seldom occurs at one local point in a system. When corrosion is directly encountered or corrosion products are discovered in a process stream, every effort should be taken to thoroughly inspect all parts of the system to determine the cause and the extent of the problem. Better still, conduct these inspections early in the lifecycle of new systems and continue this activity on a planned basis.

It may also be worthwhile to consider the opposite issue, that is, if corrosion is expected but is not observed as expected. It is important to continue to investigate why the expected corrosion is not appearing. It could be that the corrosion, or a related corrosion mechanism, is appearing at a different location.

1.4.2 Corrosion Under Deposits

Some piping systems are more prone to accelerated aging due to corrosion. Leaks can occur in older underground pipelines due to lack of cathodic protection and deteriorating coatings resulting in release of contaminated water, hydrocarbons and sewage. Corrosion Under Deposits (CUD) occurs in lines that are partially plugged with deposits such as slime, sludge and sediment as contaminants concentrate under the solid deposits and cause more rapid corrosion. This is a particular concern in upstream petroleum produced fluid gathering system piping.

1.4.3 Corrosion Under Insulation and Fireproofing

Corrosion Under Insulation (CUI) is a possibility when the equipment temperature is cool enough to condense moisture. Failure of the outer insulating cover and coating, as well as ingress of rain water can also cause of CUI. CUI is an aging issue for refrigeration equipment and insulated piping, especially in coastal regions with high humidity and salty air and the equipment temperature is cool enough to condense moisture and not cause frost. The insulation becomes water logged and keeps the moisture in contact with the metal, causing more rapid corrosion which is exacerbated by chlorides in the atmosphere or in certain types of insulation. CUI can potentially cause stress corrosion cracking in equipment and piping constructed of austenitic and duplex stainless steels due to chloride attack.

Deterioration of insulation coverings, coatings and fireproofing can allow the ingress of water (rain, cooling tower mist, deluge testing discharge) that leads to CUI. CUI is of particular concern because it is not easily detected with typical inspection techniques. In some instances, it is only detected after considerable damage has occurred.

CUI is not only an aging mechanism that occurs at low temperatures. Hot pipe and equipment are sometimes insulated, not only to conserve energy, but also to protect personnel. Another reason for CUI is the use of steam tracing. When steam tracing is used within insulation, extra precautions are needed to resist stress-cracking corrosion. Steam traced systems experience tracing leaks, especially at tubing fittings beneath the insulation. Figure 1.4-2 shows an image of external corrosion of a pipe due to leakage of steam tracing.

Figure 1.4-2. External Corrosion of a Pipe Due to Leakage of Steam Tracing (Sastry, 2015)

Steam-traced lines should be double wrapped, with the first layer applied directly to the pipe, followed by the steam tracing and then more foil over the top.

Corrosion under fireproofing (CUF) is caused by moisture being trapped under fireproofing used on structural steel supporting process equipment including pressure vessel skirts, structural platforms, pipe rack structural steel and sphere legs. Cracking or spalling of fireproofing over time allows ingress of moisture. Like CUI, CUF can be more dangerous because it often goes undetected. It is difficult to inspect and the consequences of failure may be greater.

For more discussion of CUI and CUF mechanisms the reader is directed to API Recommended Practice 583: *Corrosion Under Insulation and Fireproofing* (API 2014).

1.4.4 Manufacturing Defects

Manufacturing defects are another potential contributor to aging. A casting flaw can remain hidden for years and may suddenly trigger a fault line leading to mechanical failure in process equipment e.g., pump casings, valve bodies). With large size equipment, such defects are becoming more common. At least one significant incident in a large power plant occurred when a generator set disintegrated at high speed revealing an irregular crystal inclusion in a large drive shaft. This defect had remained hidden for years and a slight vibration problem was masked by counter balancing during initial commissioning. It may be important to fully investigate any suspicious properties or behaviors in equipment during initial commissioning since there may not be a second chance.

1.4.5 Excessive Wear and Tear

Wear and tear is another significant contributor to aging of equipment and infrastructure. Wear and tear is damage that naturally and inevitably occurs as a result of normal exposure to service conditions, upset conditions and/or extended time. Wear and tear is not necessarily a function of chronological age but rather the sum total of exposure conditions through the entire lifecycle. Despite efforts taken during design to anticipate all operating conditions, there are often abnormal (out of range of the design envelope) situations that may not be anticipated. Sometimes these are recognized while at other times they are simply missed or overlooked. These abnormal conditions can have a pronounced effect on aging.

Wear and tear is an expected phenomenon in most mechanical equipment. When equipment is directly exposed to operating and environmental conditions it undergoes change. This change may be detrimental to material properties and can lead to premature failure. The design lifecycle of mechanical equipment should consider all the factors that might contribute to wear and tear during normal and occasional upset conditions. Experience with similar systems can provide valuable insight into making such an assessment.

There are situations where excessive wear and tear is experienced. This may be the result of substandard materials of construction, improper assembly or operating exposures that were not anticipated. Excessive wear and tear should be seen as a red flag that something is out of the ordinary. Unless the mechanism contributing to such deterioration is well understood, an unexpected failure could occur at any time. Linear extrapolation of remaining life should only be applied when wear and tear correlates with past experience. Similarly, an unusual pattern of minor failures not experienced elsewhere or previously should signal that something is wrong. Increase the frequency and intensity of monitoring and consider early replacement. Better still, analyze the operation and determine the cause of the excessive wear and tear.

What is excessive wear and tear and how is it recognized? There is no simple answer that can apply to all situations. The first step is to establish what is normal based on the review of the process hazards where expected damage mechanisms are evaluated as part of the equipment design for the process. This requires a comparison against a similar system or piece of equipment in a similar operating environment. This may be difficult for unique or prototype equipment. If such a reference point is not available, one must apply experience and judgment. Another practical approach might be to consider visible markings (etching or scoring), damage, or deterioration beyond a certain percentage of that normally expected as excessive wear and tear for similar equipment regardless of service. Ultimately, the definition of excessive wear and tear and the associated response will depend on the operational risk and the willingness to tolerate a failure. Figure 1.4-3 shows scoring on a shaft.

Figure 1.4-3. Image Showing Scoring on a Shaft

1.4.6 Fatigue

Fatigue is the exposure of a structural member or component to a high number of stress cycles. Cyclic stressing is probably the single biggest contributor to aging other than corrosion. Cyclic stresses due to loading, start-ups, pressure swings, mechanical impact, temperature cycles, and wind gusts can have a more pronounced effect on equipment integrity than continuous high stress. Effects may include cracking and fatigue failure.

Cyclic stress is commonly associated with vibration in machinery and equipment which operates under repeated high load conditions. Fatigue itself is not necessarily a problem and is an expected behavior in certain operating systems. However, if not monitored, it can result in an abrupt fatigue failure. Metal fatigue is typically characterized by a breakage pattern in a single flat plane similar to a shear. Fatigue is one of the prime reasons that commercial airlines retire their aircraft after a specified number of flights. Incident statistics have shown that defects are more likely to occur in short haul aircraft exposed to more frequent take-off and landing schedules. In process facilities, cyclic stresses may be due to start-ups, pressure swings, and upset conditions.

1.4.7 Non-Metallic Aging

Material aging extends beyond corrosion and applies to many different materials. Rubber and plastic may gradually dry out and lose their properties. Surface cracks may develop and extend through the entire thickness of the material. The problem is further exacerbated when rubber is required to bend or stretch repeatedly. A rubber drive belt can dry out. Belt slippage may contribute to overheating and eventual failure. Hoses exposed to high pressure fluids or prolonged exposure to ultraviolet light can disintegrate and fail without prior notice. Even some ceramic materials are prone to deterioration as a result of prolonged exposure to other substances. Insulation on electric wiring can harden and break off. Insulation failures are common after several years of service and these can cause an electric short or ground fault. Wood and other non-metallic construction materials can rot, chemically decay or be attacked by insects again destroying the properties for which they were chosen. Wood, in particular, is subject to warping and twisting as it dries.

Glass fiber re-enforced piping is commonly used in cooling towers and fire water systems. It is very strong and robust particularly when it is loaded in a direction parallel to the fibers in the material. However, internal stresses can occur during the curing process resulting in distortion and cracking several months after the resin has set. This is particularly true with complicated shapes or manifold configurations. Studies have shown that glass fiber materials can lose 60% of their strength after one to two years of service. It is important to inspect glass fiber re-enforced piping for cracks and leaks on a regular basis. If such systems are in highly hazardous service, consider replacement with an alternate material.

Concrete is another important material commonly found in our industrial infrastructure. Although concrete seldom comes into direct contact with chemicals, electrical energy or other high energy sources, concrete is still subject to aging. A structural failure can be catastrophic. Concrete is somewhat unique in that its compressive strength actually increases with age during its initial curing cycle. This assumes that it is properly mixed. Under full and variable load conditions concrete can spall and erode. Ultimately, it will deteriorate from the outer surface and as well as internally. Exposure to road salt and other chemicals can accelerate the aging process in concrete. If the internal rebar is exposed to a corrosive environment, it also can decompose and contribute to a failure.

Passive fireproofing other than concrete is often used to protect structural members from the heat effects of prolonged pool fires. Cementaceous fireproofing has a finite life and it can crack on exposure to climatic conditions as well as mechanical impact. In a fire situation, it may not stand up to a water jet from a fire hose or monitor. Proper installation, inspection and repair should be practiced avoiding premature aging of structural fireproofing.

Common construction materials such as widow glazing and joint calking may also pose aging issues. Some window glazes contain asbestos, which may become airborne dust when the glazing dries out with age. Polychlorinated Biphenyls (PCBs) may exist in caulking materials which can leach into building material (cement and bricks), necessitating expensive remediation and disposal.

1.4.8 Aging of Physical Structures

Physical structures such as buildings, offices and shelters age as a direct result of their exposure to the natural environment. Wind speed and direction, weight of snow, hurricanes, tornadoes, earthquakes, temperature variations and precipitation can cause structural members to move or separate and building materials to deteriorate. Foundations can shift or sink causing superstructures to collapse. Doors and walls may fall out of alignment. Changes in the water table and soil erosion can compound this problem. Leakage through roofing materials can lead to water damage and mold. Ultimately, a facility might need to be abandoned for health reasons. Timely inspections and upkeep can prevent this from happening. When building repairs are deemed necessary they should be scheduled and completed. Otherwise, deterioration will continue and repairs may not be possible or practical.

Aged construction materials used in buildings themselves could represent a hazard. Are there any walls that contain asbestos or are constructed with asbestos panels? If so, these need to be removed to avoid personnel exposure. Careless removal of asbestos by untrained workers can create a greater hazard than if the asbestos were left intact. Ensure asbestos is removed properly and that all safety regulations are followed.

On the electrical side, are there any transformers or capacitors that still contain Polychlorinated Biphenyls? These fluids were previously used as a coolant and dielectric medium but are highly toxic. This material is also classified as a carcinogen. PCBs were eventually outlawed in the power industry and a substitute material was implemented. However, many PCB contaminated sites still exist in the United States of America (USA). Another hazardous material is lead based paint. The scraping and removal of this can release dust particles into the air presenting a hazard to nearby workers. Investigate whether less hazardous coatings have been applied to all plant equipment.

Roads, ditches, power lines, energy pipelines, cooling towers, operating plants, laydown yards, waste ponds, rail lines, pipe racks, conduit racks and marine facilities constitute important infrastructure for industry. A failure in any of these systems can prove costly and can directly impact the community. Of some concern is the fact that more money is spent on new (additional and add-on) facilities than on the existing infrastructure. Infrastructure is often not viewed by corporations as a direct contributor to profits. The common contributor to infrastructure aging is weather and ground movement. Rain, snow, ice and wind place thermal and mechanical stresses on the infrastructure systems listed above. Are any power lines supported on wooden poles and, if so, are they securely anchored? Has the wood been inspected and is it free from rot? Roads and ditches in particular are subject to erosion and flooding. A damaged road surface will contribute to vehicle damage and repeated usage will aggravate the problem. Proper repairs may be necessary to address current service conditions. Underground services are often exposed to unknown conditions. In many regions, the water table has shifted over time causing soil movement to occur. Many construction excavations have met with surprise to find damaged or shifted equipment below.

1.4.9 Process Chemicals Aging

Chemicals can also deteriorate with time. Slurries and chemical mixtures break down and decompose upon exposure to air and changing exposure conditions. Phase change may also occur in which a gas is released or two liquid phases separate out. Obviously, the chemical properties will also change when this occurs. Lubricants, transformer oil and heat transfer fluids are examples of chemical substances that support an industrial operation but do not come into direct contact with process fluids or product streams. As such they are an important part of the infrastructure. Sometimes these materials are corrosive or they may react directly with certain metals. If these chemicals are overlooked or ignored, they can harm the equipment in which they are contained or enclosed. Even more, if a spill takes place, accelerated corrosion can occur if the surface is not properly cleaned. It is important to regularly monitor the quality of all chemical substances whether or not they are part of the main process. If contamination or quality deterioration are noted, these materials should be removed and replaced. If equipment containing chemical solids or fluids is to be out of service for an extended period, consider replacing the contents with a more inert material. Again, regular monitoring is essential. Biohazards have recently been recognized as a significant threat to the health and safety of workers (dry rot, mold, asbestos etc.).

1.4.10 Aging of Specialized Equipment

Pumps, compressors, turbines and other specialized mechanical equipment are often comprised of several moving parts. Over the course of a normal lifecycle many of these parts will have been replaced. Seals, impellers, bearings, gaskets and wear plates likely fall into this category. However, significant questions remain. Even with good equipment records, is there assurance that the entire unit has been changed out and replaced? Are there any original parts or components that have not been inspected and potentially could fail at some point in the future? Could a pump casing or a turbine rotor fail as a result of several years of operation? Inspection programs need to be extended into those hard to reach parts of an operation to ensure that equipment is safe, reliable and continues to meet operating design parameters. A Management of Change system is needed to manage these changes and to verify compatibility with the equipment design for the intended service.

1.4.11 Obsolescence

Obsolescence is a major concern and important consideration with aging. Obsolescence suggests that a system, facility or piece of equipment no longer meets current requirements or is technically incompatible with its surroundings. Obsolescence is often the result of technical advancement and innovation. Why is this of any significance? If two or more parts of a system do not function harmoniously an incident may be more likely to occur.

Obsolescence may also be the result of inability to obtain spare or replacement parts. For example, the advancement of electronic controls over pneumatics, use of fiber optics instead of low voltage electrical, and computer consoles with graphic displays, instead of board mounted instrument panels. As technology develops, vendors and suppliers typically promote their latest products and ultimately abandon earlier designs. As customers fall into line with newer technology, there is a reduced demand for “older” equipment and associated spare parts. Simple economics dictates that this will signal the end of the line. To combat the problem of obsolescence, industrial operations will often substitute “new improved” parts or they may attempt to manufacture replacement parts in-house.

Another strategy that is often employed is to scavenge spare parts from used equipment vendors, or cannibalizing from redundant in-house equipment. This was sometimes practiced by foreign domestic airlines flying aging aircraft and resulted in above average carrier accident history statistics. The challenge is that the service history of these parts is generally unknown and even with systematic inspection, conditions like metal fatigue present unknown or unacceptable risk without a history of the number of stress cycles. Also, counterfeit or used parts may not meet specifications and tend to only compound the problem. By allowing such practices, a company may be knowingly or unknowingly accepting a high level of risk.

There was a case involving a company division, whose product line profitability was in decline. The Waste Water Treatment (WWT) facility at one of the division's plants was antiquated with pneumatic control systems that were no longer supported by the manufacturer. A corporate integrity review team had flagged the issues, but the system was given a low priority for replacement. The maintenance department had to resort to cannibalizing and "replicating" spare parts to keep the facility running. Due to the makeshift spare parts degrading the functional integrity of the controls, there were frequent effluent concentration excursions.

But "new improved' parts are not necessarily the solution to obsolescence. These are often designed to match new equipment that may have different performance characteristics. New parts must also meet current industry standards which again may be somewhat different from those in place during original equipment design. New improved parts must be compatible in a number of key areas including size, units of measure (English or Metric), materials of construction, joints and fasteners, functionality, software and sensitivity to environmental conditions.

There are some simple concepts to remember. Substitution introduces something that is different. Difference equates to change. A significant number of incidents in the process industries trace their roots back to change and an ineffective "Management of Change" system. To conclude this discussion, it is wise to reflect on the simple fact that: "newer and better" is not always safer!

1.4.12 Redundancy

There are different definitions for the concept "redundancy". The first concept refers to a term closely related to obsolescence. In this case, redundancy suggests that equipment is no longer required. This is often not related to the condition of the equipment but to the market or business needs. Such equipment or facilities may then be retired from useful service or left in a standby condition to support a system failure. In a standby mode, it is essentially in service and it is typically configured into an operating system by means of piping or electrical power. This equipment should be available for full service on short notice. An example of retirement mode might be a registered pressure vessel that is deemed as surplus equipment. Obsolete equipment often falls into the redundant category but the converse is not necessarily true.

Equipment becomes redundant when it no longer meets the business or service requirements of an operation. Common causes of equipment redundancy include inadequate size or capacity as well as inability to meet current operating conditions (temperature and pressure). If redundant equipment cannot serve a useful purpose in the future, it should be dismantled and disposed of in a responsible manner. One precaution when removing redundant equipment is that "dead legs" created in the remaining isolated piping need to be eliminated. Such dead legs are susceptible to failure due to freezing, vibration and accelerated corrosion.

Simple abandonment is not acceptable in many jurisdictions. Abandoned equipment is a magnet for vandals and wildlife. It can also breed biohazards which are harmful to workers and the general public. Abandoning equipment in place also carries with it some potential negative side effects such as: 1) Potential damage to operating equipment if there is a structural failure of abandoned equipment. 2) Overall impact on psyche of the workforce because of the physical appearance of the abandoned equipment. Many operations store redundant equipment in a laydown yard for possible re-use in a future application. If re-use fails to occur, redundant equipment may capture some value as scrap through a waste recycler.

The second meaning of the word "redundancy" refers to a part in a machine or equipment that has the same function as another part, which leads to greater reliability and having the spare or stand by part available. In this case, the equipment may be considered redundant but not yet obsolete. If redundant equipment might serve a secondary backup purpose or may enter into a new lifecycle it must be carefully managed and included in an Asset/Mechanical Integrity Management program. Left idle for a considerable period of time it will be continually exposed to changing environmental conditions and could further deteriorate. In fact, sometimes this deterioration may be more serious than if the equipment had been left in service. This may make it unsuitable for future use. Redundant equipment should be cleaned and properly sealed off to prevent unauthorized tampering or entry. Consideration should be given to introducing an inert purge or medium. The equipment should also be inspected, tested and maintained as part of the asset integrity program at regular intervals to gauge whether deterioration is taking place to verify the equipment will be fit for service if needed.

Equipment components and service items that have never been used are also susceptible to aging. This includes spare parts, stored equipment and chemicals and fluids in warehouses. Long, large, replacement rotors for compressors and turbines may deform. Electronic components may degrade due to environmental conditions. Lubricants have a shelf life and will deteriorate with age, hindering their properties.

1.4.13 Brownfield Construction

The challenges of brownfield construction are all around us. Brownfield construction involves physical work in an area currently or previously occupied by process facilities and equipment. Sometimes the work is done while existing equipment is fully operational. Seldom are new operating facilities constructed in an untested region. Regulatory approvals, cost and lack of skilled manpower have hindered greenfield construction. The lure of "adding to what currently exists" has become the current trend in industry. While this strategy is somewhat questionable from a risk consolidation point of view, it sometimes helps to achieve a level of consistency in the way facilities are operated. The benefits seem to end there. Building new on top of old extends the life expectancy of existing facilities. Apart from compromises in spacing guidelines, brownfield construction often requires numerous physical tie-ins to live equipment and existing support systems. Is the existing equipment and infrastructure suitable to support a major capital project? Are flare lines and sewers adequately sized to handle an upset condition or release? Can new piping be welded into existing piping circuits? Is there enough metal thickness remaining to ensure proper penetration welds? Will electrical systems and instrumentation be compatible with those in the existing facility? Is there enough strength and capacity in the pipe racks and cable trays? More important, has a thorough condition assessment been conducted on all equipment that will possibly need to support altered operating conditions for an extended time period?

Aging equipment, facilities and infrastructure will always be a reality in our changing society. We all have a responsibility to pitch in and contribute to making it safe and reliable. We must avoid the urge to focus only on the newly constructed or newly acquired facilities which often have more desirable features. Unless there is a compelling safety or economic driver, the lifecycle of aging equipment and infrastructure can and should be considered for future extension. We as individuals, our companies, industry and regulators should report any equipment problems or deficiencies to those in authority so that timely maintenance and repairs can be provided.