ASSET INTEGRITY

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1.0 SCOPE

The purpose of this data sheet is to provide general guidance for the development and implementation of effective loss prevention asset integrity programs for systems and equipment.

Recommendations for inspection, testing, and maintenance (ITM) program tasks for specific systems and equipment can be found in the data sheets for those systems and equipment.

Design of systems and equipment is beyond the scope of this data sheet. However, decisions made at the design stage can greatly impact the scope, implementation, and effectiveness of the ITM program and thus equipment reliability. Information on the design of maintainable assets can be found in equipment-specific data sheets, OEM guidelines, industry practices, and/or applicable codes and standards.

1.1 Hazards

A viable asset integrity program is essential to sustaining reliable operation of site processes, including production, utility, and support systems. This management system uses design, operational, and ITM data to ensure the reliability of the equipment, reducing the likelihood of equipment breakdown, and keeping energy sources contained. Equipment breakdown and subsequent property damage and interruption to operations can result from inadequate asset integrity programs.

1.2 Changes

July 2024. Interim revision. Minor editorial changes were made.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

The goal of an asset integrity program is to ensure production, utility, and support system equipment operates reliably and remains fit for the intended service. At the core of this program is the inspection, testing, and maintenance (ITM) program that assesses the condition of systems and equipment to identify and manage any deficiencies before breakdown occurs. A well-functioning asset integrity program requires a collaborative effort between all departments within a facility, including management, operations, engineering, and maintenance.

Development of the asset integrity program may take different paths for different industries. Some industries have well-defined processes and predictable damage mechanisms detailed in industry standards. Other industries may rely on independent evaluations to determine the potential damage mechanisms because industry standards are not available. In either case, the information used when developing the asset integrity program needs to consider the unique hazards present.

2.2 Equipment and Processes

2.2.1 Identify the hazards to which the production, utility and support systems and equipment are exposed to based on the process. Ensure these hazards are understood and information about them is available to company personnel.

2.2.2 Evaluate and control these inherent hazards through design and operational parameters wherever possible. When processes, systems, or equipment are repaired, altered, refurbished, or replaced, or changes in the service or operating regime occur, reevaluate the presence of these hazards and the evaluation/control methods used. This includes verifying the scope and implementation of the asset integrity program.

2.2.3 Design and install equipment to allow inspection, testing, and maintenance (ITM) activities to occur throughout the equipment's service life (i.e., design for maintainability). When processes, systems, or equipment are repaired, altered, refurbished, or replaced, manage these changes with the same consideration for the need to be able to effectively perform ITM activities.

2.2.3.1 Where necessary, provide a method to measure process-based interval tracking (e.g. throughput, operating hours, starts) in order to determine when ITM activities should be triggered. Where possible, store this operating data for the service life of the equipment.

2.3 Human Factor

2.3.1 Asset Integrity

Effective asset integrity programs verify that mechanical, electrical, pressure and production equipment, as well as their associated systems, are adequately designed, installed, operated, maintained, and protected. Asset integrity programs aim to identify deficiencies in their emerging stages and correct the deficiencies at the optimal time throughout the equipment service life (see Section 3.3.1.1 and Figure 3.3.1-1 for more information).

2.3.1.1 Asset Integrity Program

2.3.1.1.1 Ensure personnel involved in all aspects of the asset integrity program have the required training and possess the expertise and skill required by the complexity of the tasks being performed. This includes engineers, operators, designers, contractors, and vendors.

2.3.1.1.2 Establish and implement a documented asset integrity program to ensure the integrity and reliability of the production, utility, and support systems and equipment. Key items for a successful program include the following:

A. A culture in which asset integrity is highly valued

B. Support and commitment from all levels of the organization, including management with clear levels of responsibility and accountability in place

C. A written policy statement that clearly defines the goals of the program, including risk tolerance and the desired reliability levels

2.3.1.2 Inspection, Testing, and Maintenance (ITM) Program

2.3.1.2.1 Develop, gather, and maintain current all information necessary to establish and implement the appropriate ITM activities and strategies to maintain equipment integrity and reliability throughout the equipment service life.

A. Develop a method for identifying, detailing, and tracking the systems, equipment, and components covered by the asset integrity program. Include the associated production/process flow diagrams, piping and instrumentation diagrams (P&ID) and utility and support system one line diagrams for the systems, equipment, and components.

1. Provide unique and recognizable identifiers for equipment and components.
2. Detail any pertinent information from the design and commissioning of the equipment, as well as enough information to order parts or perform repairs/alterations.
3. Perform updates when equipment or components are added, removed, or replaced from the systems.

B. Prioritize systems and equipment considering the consequences of a breakdown. This is based on a systematic risk evaluation of the site, including the production, utility, and support systems.

C. Identify the inherent process- and equipment-dependent hazards and resulting damage mechanisms and failure modes that need to be evaluated throughout the service life of the equipment to verify equipment integrity for the intended service.

D. Identify the intended operating parameters/regime, including ramp rates for all operating regimes and integrity operating windows.

E. Consider the guidance supplied from applicable regulatory groups, codes, standards, operating history, insights from plant personnel, industry practices, equipment-specific data sheets, and original equipment manufacturer (OEM) guidelines.

2.3.1.2.2 Establish and implement an ITM program using the information in Section 2.3.1.2.1.

A. Determine the appropriate ITM activities and strategies to implement, using a consistent approach for determining which activities are necessary. Include baseline activities as well as the intervals or conditions that would trigger periodic activities. Several ITM strategies may be implemented to ensure the integrity and reliability of equipment.

1. Where a reactive (breakdown) ITM strategy is used, do the following:

   a. Provide a means of identifying that equipment has failed in order to facilitate the repair/replacement of the equipment.

   b. Ensure personnel are available to either repair or replace the affected equipment within an acceptable time from when the equipment fails.

   c. Ensure supplies (tools, equipment, parts, and consumables needed to perform the repair/replacements) are available and viable for access within the timeframe necessary to address the failure and to deal with successive failures.

2. Where a preventive ITM strategy is used, do the following:

   a. Plan ITM activities in advance, using a trigger to initiate the activity. A trigger may be a time-based or a process-based interval (e.g., throughput, operating hours, starts).

   b. Have equipment serviced when triggered by the interval, independent of the condition.

   c. Ensure the intervals used to trigger ITM activities are reliable. Multiple process-based intervals may be used to trigger the same ITM activity. In such cases, ensure all intervals are reset once the ITM activity is completed.

   d. Perform baseline ITM activities of equipment to act as a starting point for trending or comparison. This includes baseline inspections of newly fabricated/repaired/acquired equipment and baseline testing of equipment sensors.

   e. Provide a means of identification that equipment has triggered a process interval in order to facilitate an ITM activity.

   f. Ensure personnel are available to perform the ITM activity within an acceptable time from when the process interval is triggered.

   g. Ensure supplies (tools, equipment, parts, and consumables needed to perform the ITM activity) are available and viable for access within the timeframe necessary to address the ITM activity.

3. Where a predictive and/or condition-based ITM strategy is used, do the following:

   a. Correlate monitored conditions that trigger ITM activities to the damage mechanism the ITM activity will address.

   b. Perform baseline ITM activities of equipment to act as a starting point for trending or for comparison. This includes baseline signals for condition monitoring and baseline testing of equipment sensors.

   c. Ensure personnel evaluating the monitored variable(s) have proper training and expertise.

   d. Ensure monitoring will minimize the possibility of producing false alarms.

   e. Determine the acceptable safe operating limits (upper and lower absolute values as well as rate of change) for each variable monitored, and define acceptance criteria at which the ITM activities will be triggered.

   f. Have conditions monitored, sampled, and trended at appropriate intervals in order to adequately recognize conditions outside the acceptance criteria and provide sufficient warning that action can be taken prior to failure (early detection).

B. Develop detailed descriptions of each ITM activity to be performed as a part of the ITM program. If detailed OEM recommendations, industry practices, and/or applicable codes and standards are available, they may be sufficient to supply preventive or condition-based ITM guidelines.

C. Define the acceptance criteria for ITM activities where the results will be evaluated.

2.3.1.2.3 Perform and document ITM activities in accordance with the ITM program.

A. Implement a process to track ITM activities to completion once they are triggered.

B. Review and evaluate ITM results immediately upon receipt in order to ensure any corrective action(s) necessary can be taken.

1. When results from the ITM program deviate from the acceptance criteria, follow a deficiency management process (see Section 2.3.1.4 for more information on deficiency management). Ensure the deviation is communicated to operations. If the deviation occurs while the unit is in operation, the severity of the deviation needs to be quantified to determine if shutting down the unit is necessary.

C. Monitor and trend equipment conditions and performance as follows:

1. Monitor operational data to ensure equipment stays within its operating parameters, and identify when the operating parameters are exceeded. If equipment exceeds operating parameters, determine if adjustments need to be made to the ITM program and assess impacts to the remaining useful life of the equipment.

2. Monitor condition and performance results and trends for processes, systems, equipment, and ITM program actions. Where results and trends deviate from the acceptance criteria or indicate accelerated rate of equipment deterioration, evaluate if further action is necessary and/or adjustments need to be made to the ITM program. A fitness for service (FFS) evaluation is performed when the ITM program identifies one or more conditions outside acceptable limits, and repair, alteration, or replacement is not going to be performed prior to restarting. See 2.3.1.4.1(A) and 3.3.1.3(A) for additional guidance.

D. If ITM activities need to be deferred, identify the consequence of not completing the activities during the timeframe specified by the ITM program prior to selecting which activity to defer.

E. Track deferred work through to completion.

F. Evaluate program results and trending for impacts on the program scope/strategy.

Evaluate ITM program scope, frequencies/intervals, strategies to effectively identify damage mechanisms as required taking a condition-based approach based on ITM trending, fitness for service, remaining useful life and/or root cause analysis results.

Consider the impact of changes in operating parameters/regime and integrity operating windows on the damage mechanisms and the ITM program scope. This includes impacts of equipment changes due to upsets/trips/forced outages/hard crashes and/or breakdowns.

Consider the cumulative impact of the contributing factors on service aging on the ITM program scope.

2.3.1.3 Equipment Service Aging and Remaining Useful Life

To maintain integrity and reliability throughout the service life of equipment, service aging needs to be effectively managed. Evaluate the deterioration of equipment created by the process- and equipment-dependent damage mechanisms in place over the service life of the equipment. Use a condition-based approach to determine the impact of service aging on the remaining useful life of the equipment. Evaluate the cumulative impacts of the following contributing factors on equipment service aging and the remaining useful life. Figure 3.3.1.2.7 shows the interaction of the contributing factors impact on equipment service aging.

- Physical, operating, and environmental service conditions
- Operating history (including condition and performance monitoring trending)
- ITM program evaluation results and trending (including fitness for service)
- Chronological age and service life

A remaining useful life (RUL) study is performed based on the condition-based evaluation of these contributing factors (including fitness for service evaluations) to determine how much of the service life remains for the equipment. Consider repair, alteration, refurbishment, and replacement options to maintain operational integrity of the equipment to reduce the likelihood of a premature failure in service. Replacement of key deteriorated components can extend service life. Figure 3.3.1.3 shows the interaction of equipment conditions, including service aging contributing factors, operating history, ITM results and trending, and fitness for service evaluation results which impact performing an RUL study.

Consider the lead time for replacement equipment, particularly if equipment is to remain in service until the replacement equipment is installed. Consider an equipment contingency plan to prepare in advance the response to a premature failure of the equipment in service, addressing any gaps between the RUL timeframe and the replacement timeframe.

See 2.3.1.4.1(D) and 3.3.1.3(C) for additional guidance on RULs and 3.3.1.2.5, 6 and 7 for additional guidance on equipment service aging. See 2.3.2, 3.3.2, and the applicable data sheets for specific equipment contingency planning guidance.

2.3.1.4 Deficiency Management

2.3.1.4.1 Establish and implement a deficiency management process as part of the asset integrity program to ensure all equipment condition deficiencies identified are evaluated and tracked to closure. A typical deficiency management process includes the following elements:

A. Fitness for Service (FFS) Evaluation

Perform an FFS evaluation when the ITM program identifies one or more conditions outside acceptable limits and repair, alteration, or replacement is not to be performed prior to restarting. FFS evaluations may not need to be completed if timely corrective action is to be taken, including performing a repair, alteration, or replacement to bring the equipment back to a condition acceptable for the intended service.

B. Repair/Alteration/Re-Rate/Replacement

1. Use equipment-specific data sheets, OEM guidelines, industry practices, and/or accepted engineering codes and practices when possible, when performing any corrective action to equipment.

2. Use a management-of-change (MOC) process when corrective actions involve altering equipment or replacing equipment with something other than “replacement in-kind.”

3. Perform QA/QC checks to ensure the work is performed as required. This includes performing inspection and testing to ensure repair work is of acceptable standards and is suitable for the intended operation upon the completion of the work.

4. Incorporate the results of the ITM program to influence the design of alterations or replacement equipment.

5. Establish and record new baselines for monitoring.

C. Operating Parameter Re-Evaluation

Determine if the operating parameters of the system need to be adjusted based on the deterioration revealed, the condition of the equipment, and the intended service going forward.

D. Remaining Useful Life (RUL)

Perform an RUL study when deterioration has exceeded predetermined acceptable limits but is still considered fit for service. This study may also be performed when suitability of the equipment to operate for the intended duration is in question. This includes the cumulative impact of service aging on the remaining useful life for the intended service. The RUL study is primarily applicable to fixed and rotating mechanical equipment. However, there are life prediction analyses that may be applicable to other types of equipment.

1. Ensure data accuracy and relevancy. Use actual measured data whenever possible. When using supplied or averaged data in lieu of measured data, the calculated deterioration rates may not be indicative of the actual conditions. Similarly, comparing trended data from the same location on equipment may be critical to ensuring data accuracy, depending on the deterioration method.

2. Calculate a reinspection interval for the revealed deterioration. Base the interval on the RUL calculation, anticipated operating regime/ conditions and guidance from equipment-specific data sheets, OEM guidelines, industry practices, and/or accepted engineering codes and practices.

2.3.1.5 Root Cause Analysis (RCA)

2.3.1.5.1 Perform RCA and create corrective action items from the RCA findings, if necessary. Develop specific recommendations and corrective action to prevent recurrence or similar incidents. Metrics of measuring success from a corrective action as a result of an RCA should be developed to confirm the intended effect. These action items may be either physical or procedural changes and should use the MOC process to ensure safety and to be tracked to completion.

Situations that typically warrant an in-depth RCA include when equipment fails prematurely, when equipment fails in a way that was not anticipated or predicted based on the hazard analysis, when excessive or unpredicted deterioration is revealed, and/or when equipment operates outside its operating parameters unexpectedly. If a condition that is predicted by the asset integrity program occurs within the predicted timeframe and in the predicted manner, an RCA may not be necessary. The level of scrutiny applied during the RCA may vary depending on the circumstances of the ITM program results. Effective RCA's support continual improvement and evolution of the asset integrity program.

2.3.1.6 Documentation Requirements and Trending

2.3.1.6.1 Document each ITM activity and any subsequent deficiency management activities and RCA.

2.3.1.6.2 Trend the results of the ITM activities to identify any significant changes in equipment conditions to help predict/identify potential failures before a failure occurs in service.

2.3.1.6.3 Using all of the data collected from the ITM program and deficiency management process, reevaluate the hazard identification and evaluation process (Sections 2.2.1 and 2.2.2). This may affect the ITM activity scope and frequency.

A. Update ITM frequencies/intervals, strategies, and methods based on RCA information, operating parameters, and when repair/alteration/re-rate/replacements occur.

B. Incorporate information into the asset integrity program to reflect actual conditions to be considered for new designs.

2.3.1.7 Auditing

2.3.1.7.1 Conduct program audits and prepare audit reports. Have audits and reports performed by experienced personnel, preferably from outside the maintenance organization. Include full reviews of the necessary records to accomplish the specific goals of the audit.

A. Ensure frequency and depth of audits are commensurate with the results received from previous audits and the overall performance of the asset integrity program.

B. Perform an audit of the hazards to which the production, utility, and support system equipment are exposed whenever operating in a regime that was not considered during the development of the asset integrity program.

2.3.1.7.2 Where gaps are identified during audits, ensure the audit reports have corrective action items identified and tracked to completion.

2.3.2 Contingency Planning

2.3.2.1 Equipment Contingency Planning

2.3.2.1.1 Develop and maintain a documented equipment contingency plan (ECP) as part of a business continuity plan (BCP) to minimize the equipment downtime and reduce the exposure to key site processes, including production, utility, and support systems.

As part of the ECP process, perform a systematic assessment of site processes and systems to identify equipment considered key for the continuity of operations (i.e., critical asset list).

Evaluate equipment breakdown scenarios and business interruption exposures for this equipment. Consider process bottlenecks, single points of failure, unique and long lead time equipment, evaluate equipment integrity, reliability and remaining useful life, fitness for service, and operating history/trends, and service aging. Evaluate the type and scope of ECP needed to mitigate the equipment specific breakdown exposures. For all equipment in the ECP, maintain equipment information described in Section 3.3.1.2.1.

The ECP includes recovery options/mitigation strategies to respond to and recover from the equipment breakdown exposures, which can include repair/replacement/rental lead time options, used and/or surplus equipment, redundancy, and sparing to minimize the downtime.

Evaluate transportation and removal/dismantle, installation/handling and specialty labor requirements unique to the equipment as part of the ECP. See Section 3.3.2.

If vendors are required to perform any task associated with the implementation of the ECP, do the following:

A. Ensure they are pre-qualified to any potential OEM guidelines and/or applicable codes and standards (e.g., RAGAGEPs). This includes any corporate standards and/or guidelines.

B. Ensure they can provide any specialty labor/tooling requirements unique to the equipment.

Determine if the equipment requires any specific commissioning/pre-startup safety review processes as part of the standard operating procedures required by the equipment/process as part of implementation of the ECP.

2.3.2.1.2 For an ECP to be considered viable to minimize the equipment breakdown downtime and reduce the exposure, the following must be true:

A. The ECP documents the plan to respond to and recover from an equipment breakdown to minimize the downtime.

B. The ECP has considered equipment conditions, breakdown scenarios, exposures and process impact of an unplanned outage for equipment considered key to the continuity of operations.

C. ECP mitigation options/strategies have been developed for the key equipment and have considered repair/replacement/rental lead time options, used and/or surplus equipment, redundancy, and sparing where needed

D. Equipment design/specification/installation information and contract/service agreements with the OEM and/or vendors are in place where needed as part of the ECP.

E. The ECP includes verified procedures for transportation and removal/dismantle and installation/handling requirements for the key equipment.

2.3.2.1.3 Review, test and validate the ECP annually to manage change, maintain viability, and confirm efficacy. Also review, test, and validate the ECP when there are significant changes on site, including the following:

A. Spare(s) are put into service or are being repaired and are no longer available/viable.

B. Spare(s) are not stored or maintained as viable.

C. There are changes in processes, revenue flows, and equipment conditions.

2.3.2.2 Sparing

2.3.2.2.1 Sparing is one of the mitigation options/strategies that can be used to recover from an equipment breakdown. Store spares (complete spares and/or spare parts) provided to reduce equipment downtime in the event of a breakdown in accordance with the manufacturer's instructions, and protect them against physical damage and/or contamination. Inspect, test, and maintain spares per the manufacturer's instructions as part of the asset integrity program to maintain viability and fitness for the intended service.

Review the design/rated capacity/physical characteristics of the spares as compared to the equipment in service to verify compatibility. This is to ensure the spares will be able to be put into service to restore normal operations if needed to recover from an equipment breakdown. This includes identifying the need for repairs/alterations to the spares to restore conditions.

“Routine spares” are consumables and, as such, are not considered to reduce equipment downtime in the event of a breakdown. Routine spares are expected to be put into service under normal operating conditions over the course of the service life of the equipment. This includes sparing recommended by the original equipment manufacturer. “Equipment breakdown spares” are intended to be used in the event of an unplanned outage of key equipment to minimize the downtime and restore the equipment to operation. For the purposes of this data sheet, “spares” refers to equipment breakdown spares. Refer to the relevant equipment/occupancy-specific data sheets for guidance on when equipment breakdown sparing is recommended. .

For the spare equipment, maintain the equipment information described in Section 3.3.1.2.1.

Verify the location, condition, and viability of the sparing, which can be on- or off-site. Verify the sparing is owned/dedicated for the intended use.

2.3.2.2.2 For sparing to be considered viable to minimize the equipment breakdown downtime and reduce the exposure, the following must be true:

A. The spare design/rated capacity/physical characteristics are compatible with both the equipment in service and the process.

B. The location, condition, and compatibility of the sparing is verified to respond to and recover from an equipment minimize the downtime.

C. Spares are properly stored and are inspected, tested, and maintained as part of the asset integrity program to maintain viability.

D. Spares have been verified as fit for the intended service.

E. Spares are available to be put into service in the event of a breakdown of the equipment in-service.

F. A documented plan is in place for transportation and removal/dismantle and installation/handling requirements for the spares (on and off site). This includes any major modifications necessary for the spare to fit in the location have been identified and planned for (e.g., foundation, supports, frame sizes, connections to the system/process). Hardware necessary to install the spare (e.g., shim kits, couplings, cabling) is in place where needed.

The scope and implementation of the asset integrity program for equipment breakdown spares is the same program used for the equipment in-service to maintain spare viability.

Appendix C provides best practice guidance to develop ECP mitigation strategies for redundant (i.e. N+1 equipment) and rental equipment.

Refer to the equipment/occupancy specific data sheets for additional guidance on equipment contingency planning and sparing.

2.3.3 Foreign Material Exclusion

2.3.3.1 Identify equipment that should comply with a foreign material exclusion (FME) program. When identified, also determine the level of necessary FME program compliance (level 1, 2, or 3). Turbines, generators, motors, and compressors are the most susceptible to foreign object damage (FOD) due to the low tolerances in the high-speed rotating elements. However, FME should be considered whenever a piece of equipment (e.g., transformers, pressure vessels, piping systems, boilers, switchgear) is opened for inspection, testing, maintenance, and/or repair.

2.3.3.1.1 Maintain a list of equipment and systems and their compliance levels.

2.3.3.2 Implement an FME program with procedures that are strictly followed when maintenance is conducted on pieces of equipment or systems that have been identified as needing to comply with the FME program.

2.3.3.3 Perform periodic audits of the FME program structure to ensure the program is working, all critical pieces of equipment and systems have been identified, and the procedure levels still apply to the equipment.

Appendix D provides best-practice guidance for varying levels of FME scrutiny. Projects that involve major disassembly of rotating equipment, especially gas turbines and generators, should apply the guidance provided in Level 3 since introduction of foreign objects into these systems will most likely have devastating and costly effects. However, projects that involve less-extensive disassembles (e.g., to allow access only for remote inspection equipment) may apply a lesser level of FME. The overall risk involved with a potential FME event should be considered when choosing the level of protection to provide for the activity.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Loss History

3.1.1 Loss Statistics

Loss experience with maintenance-related incidents is extensive in industry. FM loss experience shows that ITM programs that are not effectively developed, implemented, and managed can adversely affect equipment losses. Loss data for a recent 10-year period indicated that inadequate asset integrity programs (e.g., lack of ITM, inadequate design, or inadequate deficiency management) were a contributing factor in most of the equipment losses.

3.1.2 Illustrative Losses

3.1.2.1 Lack of Inspection, Testing, and Maintenance Leads to SAG Mill Ring Gear Failure

A shared ownership mine produced copper concentrate and molybdenum with lesser quantities of silver and gold. The mine was an open pit mine-mill complex. Production rate was approximately 17,637 tons (16,000 tonnes) per day. The location had a single 11,000 hp (8,200 kW) semi-autogenous (SAG) mill powered by two 5500 hp (4,100 kW) electric pinion motors. The SAG mill fed two parallel ball mills. Ore was first fed through the primary crushers to an ore stockpile which then traveled via conveyor to the infeed of the SAG mill.

During start of shift circuit checks, the foreman was alerted by a loud abnormal rumbling sound. Dust was noticed falling from the bull gear cover and mill rafters. It was discovered that there was a broken ring gear tooth and the mill was shut down. Shutdown procedures were enacted and the SAG mill was cleared of all its materials. Several pieces of the broken tooth, up to 12 in. (305 mm) in length, were found in the various collection points of the lubrication system. The north pinion gear and motor assembly was shifted ¼ in due to the fracture of the tooth. Damage was revealed on the north and south pinion gears.

The entire mill operation was shut down for two months. The only reason the mill could restart after two months was that the gear was able to operate in the reverse direction until the replacement arrived. Once the replacement ring gear was delivered (4 months to receive the replacement, after being expedited), it took 4 weeks of plant downtime to install and commission the new gear on site.

When detailed testing was performed during the failure analysis, it was revealed that 24 of the 394 teeth on the gear had substantial damage. The damage was likely due to the pitch line traveling inward. Despite having to replace mating gears and running without lubrication several times in the 10 years prior to the failure, the ring gear had not been inspected in 10 years.

In this loss, the ring gear was not inspected or tested, which resulted in damage building up to the point of a tooth failing and having to replace the gear. Even though many instances of no lubrication and wearing of the pinion gears had occurred, the ITM program did not adapt to see if collateral damage had occurred. Without performing inspection, testing, and maintenance tasks that would identify the potential deterioration, the mill could not take steps to inhibit the progression of the damage or plan for the needed replacement.

3.1.2.2 No Deficiency Management of a Transformer with Internal Faults Results in Transformer Failure and Reduced Production Levels

A tire manufacturing facility produced 11,000 tires for passenger vehicles and farm equipment, and had 100% market share in its host country in addition to export sales. The site received power from the government utility through a dedicated aerial transmission line from a substation 4.3 miles (7 km) away. The site substation had a single oil circuit breaker protecting two 7.5 MVA oil-filled transformers that stepped power down from 20 kV to 2.4 kV. The use of 2.4 kV service was unique in this region and was used to power motors for Banbury mixers, breakdown mills, and other production equipment. Both transformers were needed for full site production.

Transformer oil samples were tested as a preventive maintenance practice. The dissolved gas-in-oil results showed indications of potential fault conditions in both units. It was recommended to replace the units and develop business continuity plans to recover from a transformer failure. Plant management had presented a business case for replacement, and they reconditioned the oil annually in an effort to extend the transformer life.

The plant lost power one night, reportedly due to a blackout on the utility grid. Site personnel confirmed the 20 kV oil circuit breaker and the downstream 2.4 kV circuit breakers for both transformers had opened. The differential relay had tripped for the older of the two units.

The transformers were subjected to insulation resistance and turns ratio tests and it was determined the older unit had indications of faulted turns on the high-voltage side, validating that there was an internal failure in the transformer. Even though deterioration was revealed in the transformer and the dissolved gas-in-oil results showed both transformers had indications of internal failures, the units were energized the following day with the secondary breakers open. When the upstream oil circuit breaker was closed, the older transformer emitted a loud bang and the circuit breaker was reopened.

The transformer was internally inspected through an access opening and damage to the high-voltage windings was confirmed. The transient overvoltage from the grid blackout had pushed the already deteriorated transformer to fail.

The plant was restarted the next day at approximately 40% reduced capacity with one transformer in service while repair/replacement of the damaged unit was pursued. Other accommodations increased capacity to approximately 70%. The failed transformer was repaired in about 6 weeks.

3.1.2.3 Lack of Deficiency Management Process Leads to Cooling Tower Collapse

A coal-fired electric power generation facility produced electricity using a large steam turbine generator. Cooling water for the operation was supplied by a crossflow hyperbolic cooling tower. The cooling tower was 37 years old and used a raceway constructed of redwood.

The inspection, testing, and maintenance program for the cooling tower consisted of two-year inspection intervals from the time of commissioning until three years prior to the loss. Three years prior to the loss, the inspection interval was increased three years to coincide with the major outages. A scheduled inspection had been completed four months prior to the event.

The results of the inspection revealed several critical issues with the cooling tower structure. The structure was separated from the header pipe, had bowed columns, and had failed sections on the column. The recommendation was made to complete structural upgrades before returning to service.

Only part of the repairs were performed, leading to a partial collapse that involved about 25% of the cooling tower raceway, which fell to the ground. The cause of the loss was water erosion of the raceway structural members (redwood). This reduction in structural member cross-section created a loss of structural integrity resulting in the partial collapse (7.5 weeks downtime).

The increased interval between inspections allowed for more water erosion of raceway structural members. Upon revealing the deterioration, a deficiency management process should have been applied to the inspection results to help identify if structural member cross sections were still fit for service and then determine the implications of the deterioration. Such an effort could have resulted in prompter action to correct any cooling tower inspection deficiencies and prevent a loss.

3.1.2.4 Lack of Equipment Contingency Planning Leads to Increased Business Interruption

A large, single-line kraft pulp mill that produced a nominal capacity of 900,000 tons/year (816,500 tonnes/year) of pulp had onsite electrical generation that supplied all of its electrical demands. Excess energy was sold to the grid. The electricity generated onsite was stepped up through a unique voltage ratio transformer. The transformer was four years old and had dedicated protective features as well as online dissolved gas-in-oil monitoring. There were no indications of any abnormal results from the performed maintenance, which included the following:

- Power factor testing every three years
- Insulation resistance measurements
- Ohmic resistance testing and turns to turns ratio testing every two years
- Annual insulating-oil testing
- Regular visual inspection and cleaning

During routine operation, the generator tripped and oil was found discharged from the pressure-relief valve of the step-up transformer. The online dissolved gas-in-oil detection revealed significant readings. The transformer was disconnected from the grid and the plant began purchasing power to resume operations. The transformer had suffered an internal short circuit and had several turn-to-turn failures. Additionally, sulphur content was revealed in the insulating oil, which was determined to be the cause of the loss.

The electrical breakdown of the generator step-up transformer demanded the purchase of external electricity. In addition, without the condensing of the turbine, the plant was forced to vent steam, which increased the demand on the boiler feed water treatment station. This loss also affected production. The mill was short of their planned production. Having to purchase electricity accounted for approximately half of the time element exposure.

3.2 Equipment and Processes

3.2.1 Asset Integrity Influence

The asset integrity program and its ITM program scope are influenced by many aspects within a process. Design, operating, and hazard information provides the foundational knowledge to develop the ITM program. The results of the ITM program influence the design, construction, and operation (including integrity operating windows, safe operating limits, and repair and/or alteration) of the new and existing equipment.

3.3 Operation and Maintenance

3.3.1 Asset Integrity

An asset integrity program is a key element in helping to ensure the integrity and reliability of mechanical, electrical, pressure, and production equipment as well as their associated systems. The integrity and reliability of the equipment takes into account the intended service of the equipment throughout its expected lifecycle. Promoting integrity and reliability increases efficiency and reduces equipment breakdown.

Equipment breakdown is a leading cause of loss of containment leading to fire, explosion, or other perils. Preventing equipment breakdown and keeping energy sources contained is contingent on how the equipment is designed, installed, operated, maintained, and protected. Asset integrity programs can validate the original equipment design by detecting, monitoring, and trending the anticipated damage mechanisms. These programs are flexible to manage change in the process, operating conditions, and parameters that define the ITM program.

3.3.1.1 The Asset Integrity Program

The asset integrity program impacts equipment throughout the equipment’s lifecycle. After initial design and startup, the asset integrity program implements an ITM program that focuses on equipment reliability during operation and layup periods. This ITM program takes into account the potential damage mechanisms and failure modes that are process- and equipment-dependent that may present themselves during operations. This is an evergreen process that should adapt as the equipment is service-aged and process changes occur throughout the equipment’s service life.

Lessons learned from existing equipment’s operating history should be incorporated into the design and asset integrity program for similar new equipment experiencing similar conditions.

The asset integrity program needs to effectively manage key elements which interact as process steps in the development and implementation of a viable program.

The foundation of a viable program is the **Responsibility and Accountability** element, which is the initial process step, providing the level of support and commitment required throughout the organization to effectively implement the program. See Section 2.3.1.1. The other process step elements include the following:

Identify and Evaluate

Process knowledge, operating parameters, hazard identification and evaluation process steps support the identification and understanding of what the equipment is exposed to and designed for based on the process hazards over the service life of that equipment. The includes integrity operating windows based on the operating parameters. See Section 2.2.

Mitigate

Adequate design and commissioning as a process step mitigates the inherent hazards from the process exposing the equipment. See Section 2.2.2.

Detect

Inspection, testing and maintenance programs, condition and performance monitoring based on the process and equipment dependent damage mechanisms and failure modes, and documentation and trending of results process steps directly impact the viability of the asset integrity program. This is the core of the asset integrity program. See Section 2.3.1.2.

Manage

Effective deficiency management process step, including fitness for service and remaining useful life evaluations verify asset integrity program scope and implementation is effectively managing equipment damage mechanisms, integrity and reliability. See Section 2.3.1.4.

Improve

Root cause analysis process step and the resulting corrective actions due to an equipment failure supports continual improvement and evolution of the program. See Section 2.3.1.5.

The asset integrity program process steps are detailed in Figure 3.3.1.1-1.

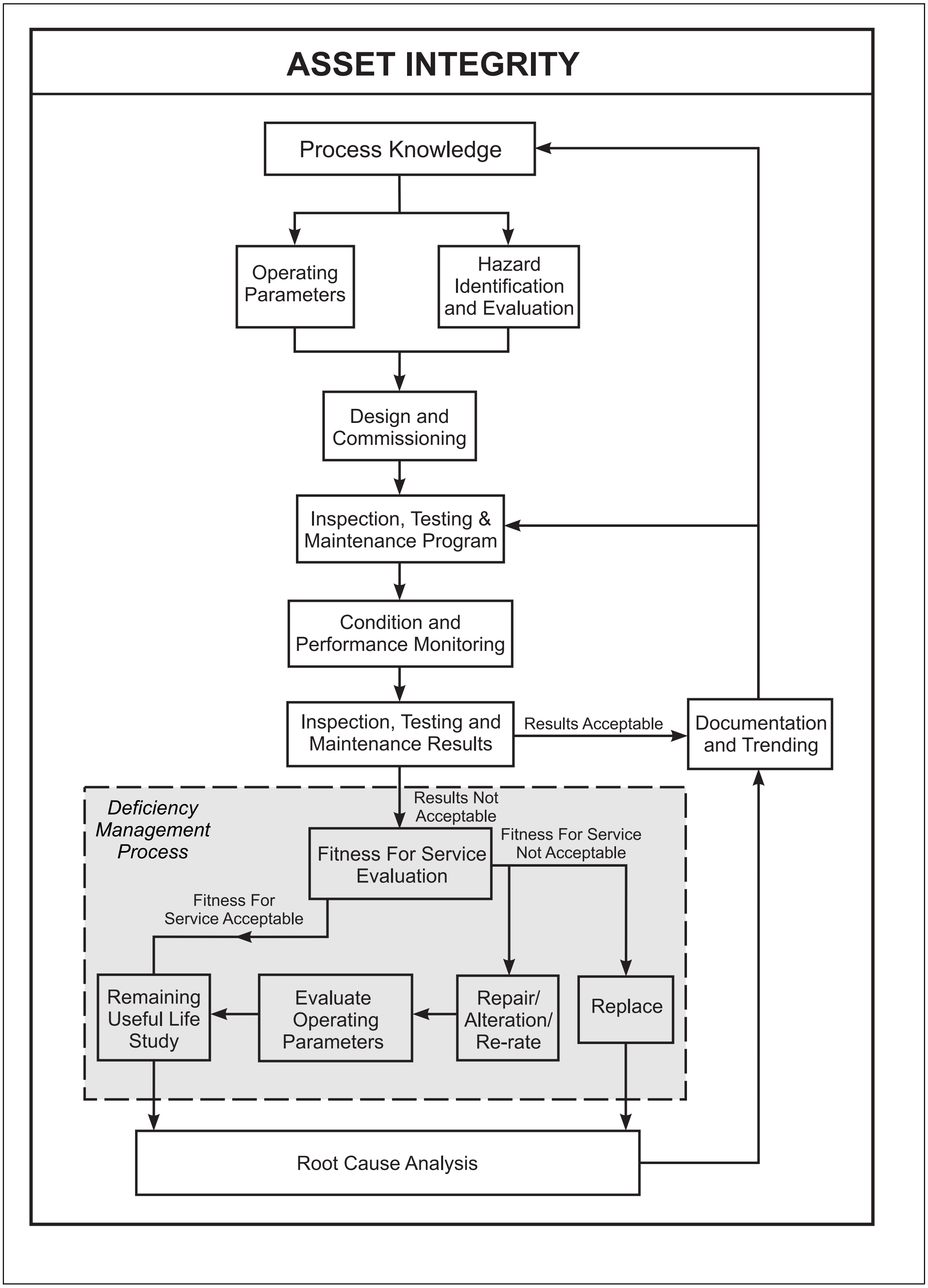

Fig. 3.3.1.1-1. Asset integrity process flow chart

3.3.1.2 Inspection, Testing, Maintenance (ITM)

The ITM program is the core of the asset integrity program. The objective of the program is to identify and implement the inspection, testing, and maintenance activities needed to ensure the ongoing reliability of equipment. The scope, techniques, intervals, and locations of ITM activities will vary depending on the equipment design, service aging, expected damage mechanisms and failure modes, and target operational availability.

It should be noted that the intervals for performing the ITM activities are typically based on a trade-off between the desired availability (risk tolerance) and the ITM costs in order to make the ITM program more cost-effective and implementable.

Each ITM activity will typically have a detailed description, including the following:

A. Direction as to how, where, when, and why the ITM activity should be performed. This may include simple instructions on a work order up to full procedures for certain activities, depending on the level of the activity.

B. The reporting required when the activity is performed. The level of detail in the reporting should be commensurate with the level of ITM activity and level of direction provided. See Section 2.3.6 for guidance on documentation.

C. The acceptance criteria to compare the results of the ITM activities against.

3.3.1.2.1 Master Equipment List

Before ITM strategies and activities can be assigned, a method for identifying, detailing, and tracking the systems, equipment, and components should be implemented in order to ensure all of the assets in the scope of the asset integrity program are accounted for. One way to do this is to develop a master equipment and instrumentation list.

This list should include all assets covered by the asset integrity program and is typically accompanied by an associated production/process flow diagram and piping and instrumentation diagram, including utility and support system one-line diagrams. Protection systems should also be included in the list. During the creation of the master equipment list, field verification of the drawings, diagrams, and P&IDs should be completed to ensure information accuracy and consistency and that the appropriate control and protective devices are in place (e.g., valves, instruments, drain caps, etc.) The master equipment and instrumentation list should provide appropriate detail to group pieces of equipment into their major components and sub-assemblies. Be sure to include redundant, spare, and/or leased equipment.

The information typically contained in a master equipment and instrumentation list includes the following:

- Design specifications
- Name plate data (manufacturer, model, serial number, date of install, material, dimensional specs, local supplier/servicer, etc.)
- Plant equipment name and number
- Location (building number, floor, etc.)
- Name(s) of individual(s) responsible and/or knowledgeable about the equipment
- Location of technical manuals, owner’s information, other documents and drawings
- A record of the equipment breakdown and routine spare availability, as well as a list of names and contact information of parts and equipment suppliers, technicians available to service, and rental possibilities (if applicable)

3.3.1.2.2 An ITM program may use a recognized strategy, or combination of strategies, for how the ITM activities are implemented. The strategies used depend on the equipment, process criticality, identified hazards, damage mechanisms, failure modes, and operating history. Additionally, it should be recognized that changes to the operation or condition of each asset can change the relevant damage mechanisms and failure modes. Therefore, any single asset could have a combination of maintenance practices and mitigation strategies employed at any stage of its lifespan. It is essential for facilities to ensure their current maintenance strategy for each asset is updated as necessary to reflect the asset’s current condition.

The three major strategies used are covered below.

A. Reactive

A reactive approach (also known as breakdown, corrective, and run to failure) consists of performing ITM activities, or repair/replacement, after a component has failed in service. Reactive is the oldest and most basic form of ITM. The action to be taken is confined to the specific failure event in order to restore the asset to an acceptable level of performance. Generally, a reactive approach is reserved for those assets that do not have a direct impact on the integrity and reliability of the overall process and should not be used for any protective systems. Components that receive a reactive approach may include assets that have redundancy built into the process, assets that have spares that are easily swapped into place during the process run, or parts that pose little consequence if they fail (i.e., not essential to the process, no significant threat of collateral damage). These types of activities may show up as “unscheduled” or “emergency” activities on work logs. If utilized as a strategy, the activities should be able to be handled in a timely manner with readily available personnel. The time in which this type of situation can be corrected is typically linked to the function of the component or piece of equipment performed within the process.

Attributes of a reactive approach:

- A reactive strategy can be less expensive (up-front costs, maybe not in the long term) to implement than other more sophisticated strategies due to needing minimal analysis and planning.
- Low initial downtime for equipment due to not taking it out of service for ITM activities.
- Typically have unpredictable failures, possibly leading to decreased availability and higher collateral costs.
- Shorter equipment lifespan.
- Damage revealed after failure may prove to be more severe than if monitored and repaired sooner.

B. Preventive

A preventive approach (also known as time-based) consists of performing maintenance activities when process intervals are triggered (e.g. number of months, number of operating hours, miles, starts, stops, etc.) in an attempt to prevent an unexpected breakdown. The concept is to prevent failures by refurbishing or replacing components before they fail by scheduling ITM activities at predetermined intervals, regardless of their current condition. It requires statistical knowledge of the phenomenon of deterioration as well as the service life of the component. A preventive strategy aims to prevent catastrophic failures and avoid any unplanned activity. Equipment downtime is typically reduced when compared to reactive maintenance. This method is most suitable when the specific causes of an asset’s deterioration and operation regime the component is subject to are well-established, consistent, and predictable.

The service life and probability of failure are based on statistical information when determining preventive intervals. This information is typically derived from OEMs and industry groups. Because of this, the data may not accurately reflect any particular operating regime at a specific location and unexpected failures may occur during service, resulting in unplanned activities and asset downtime.

Additionally, by replacing parts in a predetermined time frame, parts may be replaced long before a failure would happen. This may waste unused service life of the replaced component or performing too much maintenance which may be harmful (e.g. packing a bearing with grease too often).

Attributes of a preventive approach:

- Equipment should be exposed to a planned ITM routine throughout the service life.
- Preventive ITM can provide source data necessary for deterioration on equipment that is not being monitored.
- Preventive ITM is typically costly due to regularly scheduled activities, regardless of condition.
- Resources are needed to schedule, perform and track ITM activities
- Equipment that is running well may be disturbed for routine dismantles to the point of possible induced distress (e.g. A well running machine is dismantled for an ITM activity and is then reassembled. Damage is induced by technician error during the ITM activity.)
- Increased lifespan and reliability when compared with a reactive approach

C. Predictive and Condition-Based

A predictive and/or condition-based approach use techniques to monitor the condition of the equipment. For most equipment, when deterioration occurs, there is a loss of performance energy in the form of excessive heat, sound, movement, component wear, etc. Therefore, monitoring for the ways in which an asset may expend this energy or reveal decreased efficiency may provide early indicators of problems with the equipment. The variables that should be monitored vary depending on the asset in question and the process that asset is involved in. The information gathered by the monitoring techniques is then used to identify deterioration and trigger ITM activities. Predictive approach with extrapolate the monitored data to better predict upcoming failures. Both methods dictate that ITM activities should only be performed when necessary (prior to failure or irreparable damage).

These strategies first require the collection of measurements to ascertain when there is a condition out of range. The subsequent interpretation of the measurements determines if the condition is significant. If it is, the specific type of deterioration and the severity of the condition is then determined. This allows interventions to be planned or performed only after a decrease in the condition of the equipment has been observed and the remaining useful life of the machine is in jeopardy.

There are various strategies on how to implement condition monitoring techniques. Each component or piece of equipment may have one or various strategies of condition monitoring and various techniques in use. Regardless, the condition-monitoring techniques should be suitable to detect the different damage mechanisms typical of the asset's operating parameters for the process. Some of the different strategies are as follows:

- Continuous strategy: Continuous strategies are typically automated and provide continuous surveillance back to a central location (i.e. control room). These systems usually have high installation costs and therefore are used where equipment conditions need to provide notice within seconds.
- Periodic strategy: Periodic strategies are performed at set intervals (time or process interval based). They may have lower installation costs if they are not routed to a central monitoring location. If not monitored at a central location, a periodic strategy is typically more labor intensive due to having to collect the data in the field. These strategies are typically used where conditions may indicate the onset of issues that if ignored will lead to failure.
- Transient strategy: Transient strategies only monitor conditions during startup, shut down, alarm situations, or other transient mode of operation. This strategy may also be used during commissioning or before/after overhauls to confirm any replacements or alterations are acceptable at working loads.

Monitoring techniques that may be implemented include, but are not limited to, the following:

1. Performance monitoring: Performance monitoring utilizes various forms of condition monitoring and translates those into performance characteristics of the systems or equipment. This monitoring may be used on any component with installed instrumentation useful in evaluating the condition or efficiency.

2. Temperature Monitoring: Temperature monitoring can include thermographics and other techniques.

   a. Thermographic monitoring: Thermographic monitoring can detect electrical and mechanical defects such as excess friction, overheating, loose connections, weakening of isolations and obstructed cooling. Thermographic monitoring is typically used on bearings, motors, fuses, relays, steam pipes, drive gears, belts, couplings, generators, transformers, fuse connections, switchgear, starters, contactors and energized equipment.

   b. Spot Temperature Monitoring: Spot temperature monitoring is typically used to track temperature profiles during different operating modes and transient states. This monitoring allows tracking of specific locations that may not be available to thermographics in operation.

3. Vibration monitoring: Vibration monitoring is a very effective technique to detect mechanical defects in rotating machinery such as pumps, motors, fans, and turbines. It can identify defective bearings, imbalances, and misalignment.

4. Lubrication analysis: Lubrication analysis identify component wear, bearing wear, additive depletion/fuel dilution, coolant leaks, contamination, ingress of dirt and deterioration of internal seals. Used on gearboxes, engines, compressors, pumps, and motors. Lubrication is critical to machinery operation. Ensure a precise diagnosis for lubrication analysis and physical properties.

5. Particle analysis: Worn machinery components, whether in reciprocating machinery, gearboxes, or hydraulic systems, release debris. Collection and analysis of this debris provides information on which components are deteriorating and the rate of deterioration of these components. Used on gearboxes, engines, compressors, pumps, and motors.

6. Acoustic emission monitoring: Acoustic emission monitoring can be used to detect, locate, and continuously monitor cracks or leaks in structures, pipelines, and pressure vessels. Acoustic emissions is a screening tool, not a precision technology. Used on rotating machinery and pressure-retaining components.

7. Ultrasonic monitoring: Ultrasonic monitoring identify under-/over-lubricated bearings, wall thickness loss and subsurface defects. Ultrasonic technique is used on rotating machinery and pressure retaining components.

8. Online electrical equipment monitoring: Dissolved Gas Analysis or Partial Discharge are used to evaluate the condition of large motors and generators. It identifies voids which develop in solid insulation (delamination).

Attributes of a predictive or condition-based approach:

- Equipment is only serviced when necessary.
- Activities are performed early enough to avoid significant damage.
- Design deficiencies are identified to allow permanent repairs.
- Operating time is increased.
- Requires monitoring and analysis equipment and training.
- If data are not properly analyzed, misguided or lack of ITM activity may result, with unsatisfactory results.3.3.1.2.3 Various ITM strategies may be applied.

3.3.1.2.3 Various ITM strategies may be applied to each piece of equipment. To consistently determine which ITM strategies are used for each piece of equipment, a process of equipment prioritization and ITM strategy selection is typically implemented. This process can vary from location to location. A well-defined process for determining equipment criticality used consistently across the entire plant or operation helps to ensure consistency when comparing systems or equipment. Some examples of typical processes are covered in the following sections.

A. Documented Industry Standards

Standardized information for processes that have been in use for extended periods of time may exist. This information is typically developed and maintained by a recognized industry entity for use by owner/operators.

B. Grouping Systems and Equipment into Categories

Utilizing system and equipment grouping categories, determined by industry, to represent the level of criticality each piece of equipment has. These grouping categories may be general or complex in nature.

C. Reliability-Centered Maintenance (RCM)

RCM is a systematic maintenance process that analyzes the functions of the system. First, a critical piece of equipment is chosen, then the system that the component belongs to is defined and analyzed. The analysis identifies how the system would fail to meet its intent within the facility. The root cause for each of the ways the system could fail are determined and an ITM strategy is applied to each. The main goal is to provide operational continuity in a cost-effective manner. RCM is typically performed on rotating machinery.

D. Risk-Based Inspection (RBI) and Risk-Based Maintenance (RBM)

RBI and RBM are approaches to determining how, where, and when to inspect and perform maintenance on a facility's assets. RBI and RBM methodologies are used to prioritize ITM and were founded on the premise that the most effective use of ITM activity and dollars is to focus first on those processes, systems, or equipment that present the highest risk.

RBI and RBM are comprehensive programs requiring long-term commitment from senior management to implement and support. In these programs the risk is determined by developing failure scenarios for the processes, systems, or equipment involved at the facility. The probability and the consequence of these failures are then translated to a risk matrix which visually depicts the risk ranking of the included assets. With this matrix, it is determined which assets are above the acceptable risk level and therefore need to have mitigation technique(s) applied to lower the risk level.

3.3.1.2.4 Integrity Operating Windows (IOW) and Safe Operating Limits (SOL)

The IOW is the allowable range of the operating parameters for a piece of equipment as determined by the Hazard Identification and Evaluation (e.g. upper and lower temperature limits, minimum and maximum ramp rates, etc.). The upper and lower limits which define the IOW boundaries are also known as the SOLs.

When operated within these limits, the equipment can meet process and design parameters with a lower likelihood of breakdown. Operating outside of the SOLs (and therefore outside of the IOW) will result in accelerated deterioration and premature failure. The IOWs and SOLs are dependent on the condition of the equipment and are subject to change over time. Operators need to fully understand the equipment IOWs and SOLs as detailed in the operating procedures and training. An illustration depicting the IOW and SOL is provided in Figure 3.3.1.2.4.

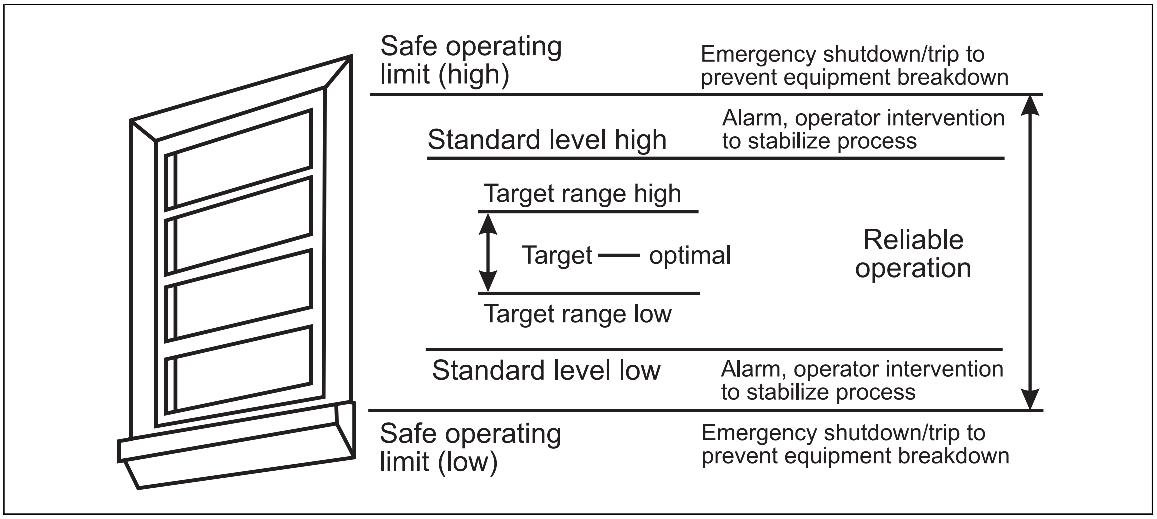

Fig. 3.3.1.2.4. Integrity operating window

3.3.1.2.5 Equipment Service Aging

Service aging is not just about chronological age. Service aging is the deterioration of equipment over its service life, which is impacted by the cumulative impacts of physical, operating, and environmental conditions, operating history, ITM program evaluation results/trending, and chronological age relative to service life. Equipment and components are designed for process/environmental-related degradations/damage mechanisms, with a certain margin/factor of safety based on prevalent standards. This allows the equipment to operate reliably according to anticipated operating conditions based on the process hazards (temperature, pressure, corrosion rate, cycles, etc.). This anticipated deterioration over the service life of the equipment is considered in the design life by the original equipment manufacturer. However, physical, metallurgical, and chemical properties of equipment materials deteriorate due the exposure to operating and environmental conditions. As a result, equipment integrity degrades over time from service aging due to these factors.

Service aging is process and equipment dependent. Equipment can experience deterioration (which may or may not be associated with the time in service), resulting in an increase in the potential for a failure in service. This depends on the extent of deterioration and damage. This can be normal service aging that is factored into the design life, or accelerated service aging, depending on how the contributing factors impact the equipment. Accelerated service aging and premature/unexpected failures can increase when these factors are improperly managed, the equipment has latent design defects, fabrication defects, and/or the design is inadequate for the process. Unexpected failures can occur even when the equipment has operated within its integrity operating window due to cyclic loading/fatigue. Operating and environmental conditions can result in potential changes in damage mechanisms that impact the service aging and remaining useful life. Changes to the operating parameters outside of the intended OEM design limits/integrity operating window can also change the damage mechanisms and the service life, increasing deterioration and potential for a failure in service.

How these contributing factors are managed impacts whether repair (if possible), alteration, or refurbishment to restore integrity can be performed, or if component replacement or full equipment replacement is required. Proper operation, and a viable ITM program can enable the equipment to achieve and potentially exceed the original design life. Conversely, improper operation and/or inadequate inspection, testing and maintenance can reduce service life. Maintaining a clear understanding of the service life status of the equipment includes consideration of remaining useful life study results.

3.3.1.2.6 Equipment Service Aging and Asset Integrity

Understanding the process hazards provides the basis for the scope and implementation of the asset integrity program to effectively monitor the damage mechanisms and impact of the contributing factors on service aging and remaining useful life. The damage mechanisms need to be fully understood, evaluated, trended as part of the ITM program, and where required, corrected to maintain equipment integrity throughout the service life.

When the asset integrity program reveals deterioration outside of acceptable limits, additional analysis through fitness for service evaluations may be required. This can result in adjustments to the ITM program. Operating procedures and/or operating parameters may require revision to ensure the equipment is maintained within any integrity operating window changes to help prevent the equipment from experiencing conditions in service, which could accelerate deterioration. A reduction in output or efficiency based on condition and performance monitoring, an increase in breakdown frequency and/or repetitive repairs can be indicators of increased deterioration that is negatively impacting the service life. Equipment repair, alteration or refurbishment may be required to restore equipment integrity. Replacement of key deteriorated components can extend the service life for the equipment. Full replacement may be required based on the RUL study results. The RUL study provides the information needed to ensure the timely replacement of service aged equipment prior to a failure in service.

To effectively manage service aging, a condition-based approach is needed to determine the impact of the contributing factors to evaluate the RUL of the equipment. This includes the analysis of ITM, condition and performance monitoring results for trending. ITM program scope and frequency may require adjustment to monitor the damage mechanisms more closely until the equipment can be repaired, altered, refurbished, or replaced.

3.3.1.2.7 Equipment Service Aging Contributing Factors

The equipment service aging contributing factors that act as risk indicators can include, but are not limited to, the following conditions:

Physical

- Mechanical property degradation
- Corrosion/erosion: Includes corrosion under insulation (CUI) and corrosion under fireproofing (CUF)
- Wear
- Thermal degradation
- Fatigue
- Cyclic stresses
- Embrittlement
- Fracture toughness
- Stress corrosion
- Oxidation
- Creep
- Hydrogen damage/attack
- Deformation/distortion

Operating and Environmental Conditions

- Operating regime/conditions, parameters, operating hours/duty cycle changes
- Process or production rate changes
- Changes in process materials
- Integrity Operating Window changes
- Operators – Inadequate SOP’s and/or EOP’s
- Overheating
- Excessive pressure
- Loss of cooling
- Vibration
- Leakage

- Misalignment
- Thermal shock
- Chemical attack
- Mechanical impact
- Lack of lubrication
- Scaling
- Loss of passivation layer
- Environmental conditions (i.e., clean, cool, tight, dry, salt air, desert sand, high or low ambient temperature, process hazardous substances, etc.)
- Persistent environment/inherent process conditions

Operating History

- Process excursions: Inconsistent operation within design limits
- Unfavorable condition and performance monitoring trending
- Unfavorable impacts due to upsets/trips/forced outages/hard crashes and/or breakdowns
- Operating history beyond design limits
- Equipment design/type/model/fleet operating history, including the impact of component upgrades/ replacement on the service life
- Increase in breakdown frequency and/or repetitive repairs/refurbishment/replacement of key components
- Unfavorable operating history compared to original design.

Inspection, Testing, and Maintenance

- Damage mechanism evaluation results/trending in accordance with the asset integrity program, with appropriate repairs, alterations, refurbishment and/or replacement of key components where required to restore equipment integrity.
- Fitness for service evaluation results

Chronological Age and Service Life

- Chronological age relative to the service life of the equipment

Chronological age is a contributing factor when evaluating service aging. The service life for equipment relative to the chronological age varies by equipment type and the operating environment, which in turn impacts the equipment deterioration over time. It is important to make the distinction between service aging and chronological age. Deterioration can progress with time, but that deterioration is influenced by the contributing factors, including chronological age. The chronological age gets to the extended exposure over time to various damage mechanisms, operating environment conditions, etc.

Figure 3.3.1.2.7 shows the interaction of the contributing factors impact on equipment service aging.

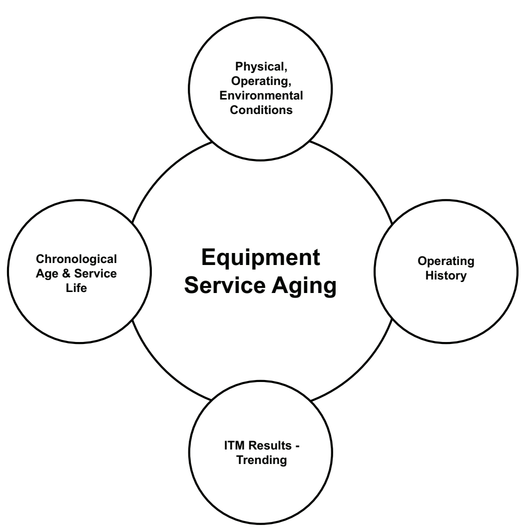

Fig. 3.3.1.2.7. Equipment service aging contributing factors

3.3.1.3 Deficiency Management

Deficiency management is a process as part of the asset integrity program to ensure all equipment condition deficiencies identified are evaluated and tracked to closure. This process begins when the results from the ITM program identifies one or multiple damage mechanism conditions/deterioration outside of acceptable limits. This process is intended to determine the implications of the revealed deterioration on the equipment service life.

A. Fitness For Service (FFS)

When the ITM program identifies deterioration or damage outside of the acceptance criteria, an evaluation of the results is performed to determine any implications. Evaluating the ITM results to determine the integrity of the equipment to continue to operate and be considered fit for the intended service or not is known as a fitness for service (FFS) evaluation. A fitness for service evaluation is a comprehensive quantitative or qualitative engineering evaluation to demonstrate the integrity of in-service equipment based on current conditions. The evaluation considers the impact of the deterioration and damage mechanism identified so proactive decisions can be made to run as-is, derate, repair, monitor or replace the equipment. The evaluation requires original design data, equipment operating and inspection, testing, and maintenance history, and the forecasted operating conditions. A typical FFS process is as follows:

1. Identify type and extent of any deterioration.
2. Determine if a FFS evaluation can be performed.
3. Determine data requirements.
4. Review available FFS techniques and acceptance criteria.
5. Perform FFS evaluation.
6. Perform any required remediation.
7. Establish need for in-service monitoring.
8. Create documentation.

Globally, the most widely used standard for FFS evaluations of pressurized and structural assets is API 579/ASME FFS-1. This standard outlines three levels of FFS evaluation:

- Level 1 is basic screening.
- Level 2 is a more detailed assessment that includes detailed calculations.
- Level 3 is the most in-depth analysis and typically includes computer-based modelling.

If the evaluation determines that the equipment is fit for service given the current condition, then a remaining life study is typically performed.

If the fitness for service evaluation determines that the equipment is not fit for service, several options are evaluated. One option is to repair or physically alter the equipment into an acceptable condition. Another is to re-rate the equipment to lower the operational stresses so the current condition of the equipment is considered acceptable (this is dependent on the process allowing this re-rating). Another option is to remove the equipment from service and either bypass it (if the equipment is not operation critical) or replace it. In each of these situations, the IOWs and SOLs for the equipment should be re-evaluated and a remaining life study is performed.

Each time a fitness for service evaluation is determined to be needed as a result of the ITM program results, a root cause analysis (RCA) and/or an incident investigation is typically performed.

B. Quality Assurance/Quality Control (QA/QC) of Replacements, Repairs, and Alterations

When deterioration is revealed, it may be necessary to perform corrective actions prior to returning the equipment to service. The extent of the corrective action will depend on the damage mechanism(s) and the extent of the deterioration.

When performing any replacements, repairs or alterations to equipment, it is important to ensure that the components/equipment used is of the appropriate type and material. To achieve this, QA/QC practices and procedures can be developed and implemented for the procurement, fabrication, receiving and storage, construction, and installation of equipment and systems. Repairs, alterations, re-rating, replacement and decommissioning of equipment and systems should also have QA/QA practices and procedures.

Verification that materials meet design specifications (dimensions, mechanical properties, and chemical composition) is part of quality assurance. This can be implemented during fabrication, at receiving, during construction/repair/alterations and/or during routine ITM activities. This may be performed using a variety of techniques to ensure design specifications are met. The most common verification practice is to confirm material chemical composition is positive material identification (PMI).

PMI is the name commonly given to the practice of physically testing a material in order to identify its chemical composition. PMI can be used to confirm that the materials of construction are consistent with the specified design either prior to or after being placed into service. PMI can be performed by various techniques. X-ray fluorescence is the most widely used portable method in the field. In a laboratory setting, a scanning electron microscope (SEM) with energy dispersive X-ray spectrometer (EDS) or optical emission spectroscopy (OES) are more common.

Different techniques of PMI can vary in the accuracy of their results. This is due to the limitations of the different testing techniques. Laboratory techniques are typically more accurate and able to detect elements with lower atomic weights.

C. Remaining Useful Life

When equipment has been subjected to the cumulative impacts of the service aging contributing factors, including operating and/or environmental conditions resulting in deterioration and service aging, the RUL of the equipment may be negatively impacted. The RUL of equipment is key to the development and implementation of a proactive asset management strategy to plan for equipment repair, alteration, refurbishment, or replacement before a failure occurs in service. The RUL is the timeframe remaining for the equipment to continue operation for the intended service. This is based on the results of an engineering evaluation as part of an RUL study.

An RUL study is a comprehensive, quantitative and/or qualitative engineering evaluation taking a condition-based approach to determine how much of the service life remains for the equipment. The RUL study could result in the development of an equipment contingency plan as needed to address gaps between the RUL of the equipment and the timeframe to repair, alter, refurbish, or replace the equipment. This is to minimize the downtime and reduce the exposure due to the premature failure of the equipment in service.

The condition-based approach utilized by the RUL study considers the impacts of the service aging contributing factors (including the physical, operating and environmental conditions), current and trended equipment ITM results (based on known characteristics of the deterioration and damage mechanisms affecting the equipment and materials of construction, chronological age and service life), operating conditions and history, and fitness for service evaluation results. Figure 3.3.1.3 shows the interaction of equipment conditions, including service aging contributing factors, operating history, ITM results and trending, fitness for service evaluation results which impacts when an RUL study needs to be performed.

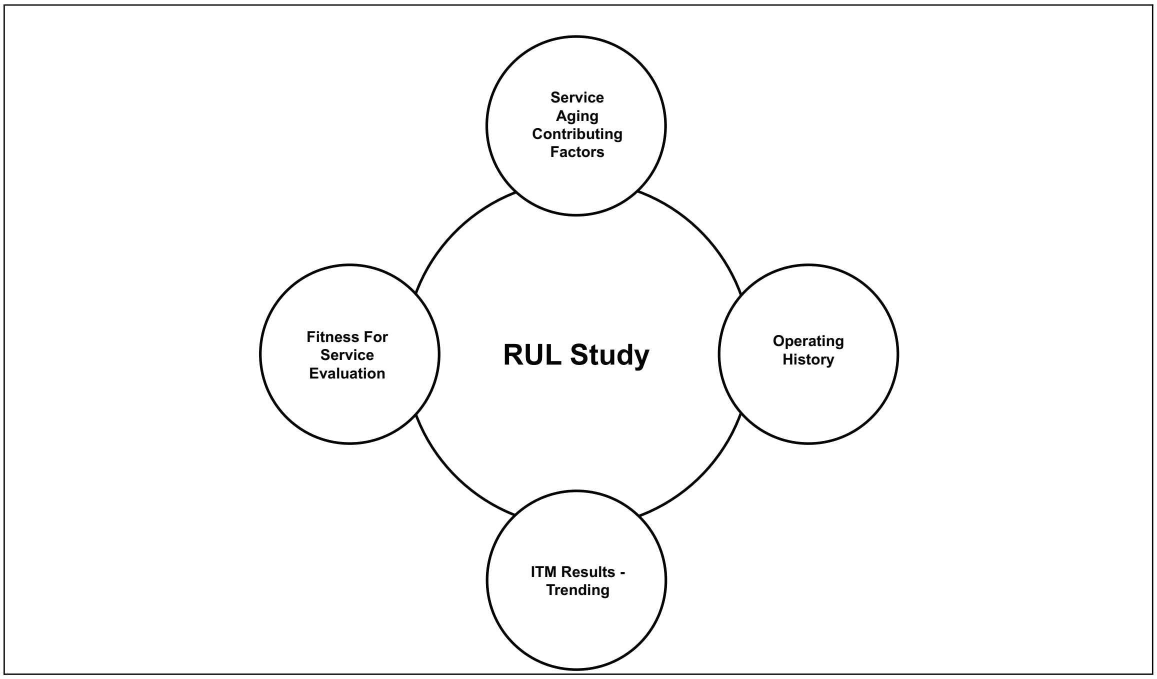

Fig. 3.3.1.3. Equipment conditions impacting performing an RUL study

The RUL study is used to estimate how long the equipment can continue in service before another planned ITM activity should be performed and/or before the equipment should be repaired, altered, refurbished, or replaced. RUL may be used as part of the deficiency management process to help determine the equipment ITM activities required. The method in which this study is performed varies between different equipment types.

Many times, it is desirable to extend the reinspection interval on a piece of equipment. In order to do this, condition monitoring equipment is typically installed in order to monitor parameters which indicate the progression of the damage mechanism(s). This will often be coupled with changes in the operating conditions to reduce the stress the equipment sees as a part of operations. This can impact standard operating procedures (SOPs), resulting in changes in SOPs and re-training of operators to fully understand the change of operating conditions due to equipment conditions.

Typically, RUL studies and FFS evaluations are performed by the OEM, qualified third-party contractors and/or a multidisciplinary team of key site personnel. This can be dependent on the type of equipment and extent of deterioration to be evaluated in determining the remaining useful life and/or fitness for service.

3.3.1.4 Root Cause Analysis (RCA)

RCA is an approach to determine underlying factors of events or conditions rather than the symptoms produced by the underlying factors. The RCA should identify the source(s) of the event or condition that, if corrected, will prevent the symptoms revealed from occurring again.

The level of scrutiny applied during the RCA may vary depending on the circumstances of the ITM program results. Depending on the criticality, consequence, and equipment history, a full RCA may not be necessary. Likewise, if a component is near the end of, or surpasses, its remaining useful life and is deteriorated by what appears to be an expected damage mechanism, the RCA may be limited and only involve confirming the damage mechanism.

Situations which typically warrant an in depth RCA include when equipment fails prematurely, when equipment fails in a way that is not predicted, or when excessive or unpredicted deterioration is revealed. RCA is typically performed as part of an incident investigation.

In all situations, the extent of the RCA should be commensurate with the criticality of the equipment or system and the consequence created by the loss.

When performing the RCA, the following are typically considered:

A. Personnel

1. The qualifications of personnel involved should be commensurate with the scale of the RCA
2. In-depth RCA can involve various specialists including NDE, mechanical/electrical engineering, corrosion/metallurgy, plant processes, plant operations, modeling experts, and management.

B. Equipment records review

1. Problem reports and repair/alteration history
2. Statement of maintenance requirements
3. Systems and equipment dismantle inspection reports
4. Original equipment manufacturer (OEM) technical letters and bulletins
5. Maintenance records, including procedural details to ensure that there are no flaws or omissions in the procedures that would allow a similar occurrence in the future
6. The backlog of related maintenance items
7. Any report(s) produced about the deterioration/failure, such as the following:

- Analysis/inspection of failed parts
- Description of symptoms
- Troubleshooting report

C. Analysis/inspection of failed parts, description of symptoms, any troubleshooting performed during operation.

3.3.1.5 Documentation and Trending

Maintaining records (historical data) pertinent to equipment covered by the asset integrity program is critical for tracking, trending, and auditing. All results from the ITM program activities, fitness for service evaluations, remaining useful life studies, and root because analyses should be documented. This is so these results may be trended and fed back into the ITM program and hazard analysis. This is performed in order to ensure that during the re-evaluations of the hazard analysis and ITM program, actual process, system, and equipment conditions and any unexpected hazards are being considered and accounted for.

Trending is the analysis of ITM results and operating parameters over a select timeframe to identify any significant changes which can be leading indicators for equipment failure. The rate (accelerating, decelerating, or remaining constant) and scope of change in ITM results and operating parameters over time are utilized to help predict/identify potential failures. This allows for corrective action to be taken prior to a failure in service.

3.3.1.5.1 The following information is typically included for the detailed documentation of an activity:

A. Technician’s name, technician’s qualifications, date, activity performed, any equipment or tools used, components affected, coverage of activity, procedure used, preparation to equipment prior to activity, as found condition, ambient conditions, activity results, units of all measurements/readings, technician’s interpretation

B. Sufficient detail that a technician of the same skill level can repeat the activity and produce comparable results

C. A unique equipment identifier for the affected equipment, as determined by the master equipment list. See 2.3.1.1.1

3.3.1.5.2 The following is a list of ways the documented data gets trended for use in the asset integrity program:

A. Compare current inspection data against baseline and previous inspection data to verify how damage mechanisms are propagating.

B. Compare condition and performance monitoring data with intended service conditions and IOWs to identify condition changes that could accelerate deterioration or be indicative of a potential concern warranting additional action.

C. Incorporate inspection results and monitoring information back into the asset integrity program to maintain program viability

D. Track completion rate of ITM activities

E. Document failure types and locations to identify systemic issues.

F. RCA and incident investigations should be retained for comparison with future events

3.3.1.6 Auditing

The auditing process can be general or detailed in nature. A general audit will look at the processes put in place and determine if they are adequate or need improvement. A detailed audit will look at details within processes and focus on how the program is performing.

Sample audit goals include, but are not limited to, the following:

- Performance indicator reviews
- RCA report reviews to ensure that recommendations have been implemented
- Review of deficiencies to ensure their status is actively being tracked, they are being tracked to closure, and closures are justified
- Review completion percentages of ITM activities and actively following up of deferred activities
- New technologies that have been implemented are producing the desired results
- Notices from OEMs and Industry bodies are being evaluated and implemented
- Whether training and practices and procedures are being followed and updated where necessary
- Whether audit recommendations are being followed

Every audit should have actionable corrective action items. These items should relate to the goals of the audit and improve on observed deficiencies. Sample corrective action items include but are not limited to the following:

- Problem equipment being replaced
- Modifications being made to equipment where necessary
- Updating procedures
- Additional training or re-training being assigned where warranted

3.3.2 Contingency Planning

The ability to recover from an unplanned outage leaving key equipment unavailable is vital to maintain the resilience of site processes. An ECP documents the planned response to recover from having equipment unavailable due to a breakdown resulting in significant interruption to key site processes to minimize the downtime. This plan is the result of a systematic assessment of site processes, focusing on identifying equipment considered key for the continuity of operations.

Actions needed to recover from the breakdown scenario to reduce the exposure include review of pertinent equipment design information and integrity/reliability. Mitigation options/strategies as part of the ECP can include equipment repair/replacement/rental lead time options, used and/or surplus equipment, sparing, transportation, and installation/handling requirements.

Transportation/handling considerations for spare or rental equipment include the following:

A. Relocating equipment within the utilization site:

1. Identify and ensure all rigging requirements are available (e.g., crane, helicopter, bridging).

2. Determine any potential need for building modifications (e.g., removal of roof, walls, equipment).

B. Transporting equipment from the holding/storage site to the utilization site:

1. Establish plans and agreements with carriers and shipping companies. Address any potential shipping problems, predetermine shipping routes and the potential need to expedite shipping. Consider any seasonal weather-related periods and remoteness of the location that could delay transportation.

2. Identify any special permitting requirements due to any of the following:

   - Transit on public roads (e.g., weight and height limits for roads and crossings; any special conveyance vehicle requirements).
   - Aerial transit of equipment
   - Transit on waterways
   - Customs requirements in between countries

The scope of the ECP is specific to the equipment breakdown scenario as part of a business continuity plan (BCP). A viable ECP will reduce/minimize equipment breakdown downtime by expediting restoration of operations.

4.0 REFERENCES

4.1 FM

Relevant equipment-specific data sheets.

4.2 Others

Center for Chemical Process Safety (CCPS). *Dealing with Aging Process Facilities and Infrastructure*. John Wiley & Sons, New York (2018).

Center for Chemical Process Safety (CCPS). *Guidelines for Asset Integrity Management*. 1st edition. John Wiley & Sons, New York (2016).

Center for Chemical Process Safety (CCPS). *Guidelines for Risk Based Process Safety*, John Wiley & Sons, New York (2007).

Health and Safety Executive (HSE). *Managing Aging Plant Summary Guide* (2010).

APPENDIX A GLOSSARY OF TERMS

Alternative service provider (ASP): An entity that is not affiliated with the original equipment manufacturer.

Asset integrity program: A management system to ensure the integrity and reliability of systems and equipment throughout the service life.

Availability: The ability of equipment or system to operate properly when needed. May be represented as the measure of the percentage of time equipment is able to be in an operable state.

Bottleneck: The slowest operation (choke point) in a process.

Condition-based interval: Intervals derived from monitoring the conditions of systems and/or equipment (e.g. temperature, pressure, flowrates etc.).

Condition-based ITM: ITM activities performed when triggered by the current condition of the equipment or system being monitored.

Condition monitoring: Monitoring of variables which indicate the operating conditions of the equipment being monitored

Damage Mechanism: A process which results in deterioration of equipment. E.g. corrosion, cracking, overheating, etc.

Deficiency: A condition revealed that does not meet the acceptance criteria set by the ITM program.

Design life: Original design timeframe established by the OEM within fixed design parameters for the intended service.

Equipment breakdown: When equipment is not able to perform its intended function at the intended capacity.

Equipment service aging: The change in conditions over time due to deterioration throughout the service life of the equipment, considering the cumulative impact of physical, operating, and environmental conditions, operating history, ITM program results/trending, and chronological age relative to the service life. Service aging is the consequence of exposure to these contributing factors, which is equipment and process dependent.

Failure analysis: A series of tests and/or examinations performed in order to determine the damage mechanisms that act upon a material.

Failure mode: The classification of how equipment reacts when it can no longer withstand the operating conditions and fails. (e.g. pinhole leak, liberation, explosion, etc.). It may also be the way a failure manifests itself (e.g., a valve may fail closed or a pump may fail to start/run). Failure causes can be mechanisms such as fatigue or corrosion or wear, human errors, overstresses, or design/manufacturing related deficiencies.

Fitness for service (FFS): A comprehensive quantitative or qualitative engineering evaluation performed to determine the integrity of equipment for continued operation in the intended service, based on the deterioration and damage mechanism outside of acceptance criteria and acceptable limits identified by the asset integrity program. The FFS can justify continued service or identify the corrective actions required to return the equipment to service.

IOW: Integrity operating window. Allowable range of the operating parameters for a piece of equipment as determined by the Hazard Identification and Evaluation (e.g. upper and lower temperature limits, minimum and maximum ramp rates, etc.). The upper and lower limits which define the IOW boundaries are also known as the Safe Operating Limits (SOLs).

When operated within these limits, the equipment can meet process and design parameters with a lower likelihood of breakdown. Operating outside of the SOLs (and therefore outside of the IOW) will result in accelerated deterioration and premature failure.

MOC: Management of change. A program to prevent introducing unrecognized hazards during a change (includes changes to technology, facilities, and/or personnel).

Performance monitoring: Monitoring of variables which indicate the performance (e.g. efficiency) of the equipment or system being monitored.

Predictive ITM: ITM activities performed when triggered by the anticipated state of the equipment based on the current condition and performance monitoring.

Preventive ITM: ITM activities performed when triggered pre-determined intervals regardless of equipment condition.

Process-based interval: Intervals derived from measurements used in the process that the system or equipment is involved in (e.g. throughput, operating hours, starts, etc.). These intervals may be used to customize preventive ITM which has historically been time-based.

RAGAGEP: Recognized and generally accepted good engineering practice.

Reactive ITM: ITM activities performed when triggered by a failure of the equipment.

Redundancy: A form a resilience that ensures system availability in the event of equipment failure. Having at least one independent back-up equipment.

Reliability: The ability of equipment or system to perform as intended for a prescribed period of time when operated within the specified environmental and operating conditions.

Remaining useful life (RUL): Also referred to as “remaining life” or “remaining service life.” Timeframe remaining for equipment to continue operation in the intended service. This is based on the results of an engineering evaluation as part of an RUL study.

Remaining useful life (RUL) study: A comprehensive, quantitative and/or qualitative engineering evaluation as part of a proactive asset management strategy, taking a condition-based approach to determine how much of the service life remains for the equipment to continue operation for the intended service – Before a failure occurs in service.

Risk: A product of the probability that an event will happen and the consequence if that event occurs.

Root cause analysis: An approach to determine underlying factors of events rather than the symptoms produced by the underlying causes.

Service life: Also referred to as “life expectancy” or ″life cycle″. Timeframe the equipment is expected to operate within the design limits (i.e., integrity operating window parameters) for the intended service. This timeframe considers the cumulative impact of the contributing factors on service aging.

SOL: Safe operating limits. See “Integrity Operating Windows (IOW).”

Trending: Trending is the analysis of ITM results and operating parameters over a select timeframe to identify any significant changes which can be leading indicators for equipment failure. The rate (accelerating, decelerating, or remaining constant) and scope of change in ITM results and operating parameters over time are utilized to help predict/identify potential failures. This allows for corrective action to be taken prior to a failure in service.

Viable: Capable of working successfully.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

July 2024. Interim revision. Minor editorial changes were made.

July 2023. Interim revision. Editorial changes were made to asset integrity program process guidance to improve clarity. Equipment service aging and remaining useful life guidance was also revised to improve clarity, including new Figures 3.3.1.2.7 and 3.3.1.3 on “Equipment Service Aging Contributing Factors” and “Equipment Conditions Impacting Performing an RUL study” respectively. A new appendix (Appendix E) was added for “Guidelines for an Audit and Inspection Program for Alternative Service Provider (ASP) Services and Components”.

July 2022. Interim revision. Made minor editorial changes.

October 2021. Interim revision. The following significant changes were made:

A. Added guidance on equipment service aging.

B. Updated guidance on fitness for service and remaining useful life.

January 2021. Interim revision. Added new definition to Appendix A, Glossary of Terms.

October 2020. Interim revision. N+1 redundant equipment guidance was updated in Appendix C.

January 2020. Interim revision. The following changes were made:

A. Revised guidance for equipment contingency planning and sparing.

B. Added guidance to evaluate the viability of equipment contingency planning and sparing.

C. Relocated guidance on sparing and transportation from Appendix C to Section 2.0 and 3.0.

July 2018. This document has been completely revised. The following major changes were made:

A. Changed the title of the document from Maintenance and Inspection to Asset Integrity.

B. Consolidated information from previous data sheet into a more organized and concise format.

C. Removed redundant information.

D. Deleted support material that did not enhance the understanding of the recommendations.

E. Added sections on asset integrity, deficiency management, and root cause analysis.

January 2014. Added Section 2.5, *Foreign Material Exclusion (FME)* and Appendix D, *Foreign Material Exclusion Procedure*.

April 2011. Changes include the following:

- Recommendations have been added for critical plant machinery and high-risk equipment in critical applications.
- New recommendations have been added for managing maintenance and services.
- Technical guidance has been added for time-based and condition-based maintenance programs.

May 2003. Revised section titled ‘‘3.1 Loss History’’. Also made minor editorial changes.

September 2002. An FM Global overview of Risk Based Inspection was added as Appendix C.3, *Risk Based Inspection an FM Global Overview*, and a reference to this Appendix has been added to Recommendation 2.2.1.4. Also, the title and Scope of this Data Sheet have been editorially changed from *Maintenance* to *Maintenance and Inspection* to highlight the importance of inspection in any maintenance program.

May 2001. Editorial changes only. No technical changes were made.

January 2000. The January 1995 edition of this document was reorganized to provide a consistent format. No technical changes were made.

APPENDIX C EQUIPMENT CONTINGENCY PLANNING

C.1 ECP Process

The process of developing and maintaining a viable ECP includes the following steps:

1. Establish a multidisciplinary team to conduct a systematic assessment of the resiliency of site processes as part of equipment contingency planning.

2. Review/develop production flow diagrams covering the entire process, including production, utility, and support systems and associated equipment.

3. Identify systems and equipment considered key to the continuity of operations. Consider process bottlenecks, single points of failure, unique and long-lead-time equipment, equipment remaining useful life, fitness for service, process hazards, and operating history/trends to evaluate the equipment breakdown risk. These are risk indicators of the vulnerability to a breakdown.

4. Evaluate the breakdown scenarios for this equipment, and the resulting exposures.

5. Evaluate the ability to recover from the equipment breakdown. Develop mitigation strategies, which can include sparing (complete spares and/or spare parts on or off site), N+1 built-in redundancy, repair and

replacement options, rental equipment, used and/or surplus equipment. Consider original equipment manufacturer sparing recommendations. Review any long-term service agreements that could support mitigating the equipment breakdown scenario.

6. If spares or redundant equipment are provided, review the asset integrity program to maintain their viability.

7. Develop, verify, and maintain key equipment design, installation, and commissioning information.

8. Review transportation, handling, installation, and commissioning requirements, including any necessary special permits.

9. Pre-qualify and train plant personnel, contractors, and vendors on the scope and implementation of the ECP.

10. Develop a documented ECP to recover from the equipment breakdown. Review, test, and validate the ECP annually to manage change and confirm efficacy of the plan.

C.2 Redundancy and Rental Strategies

This guidance represents best practices to evaluate and validate various ECP mitigation strategies for redundant and rental equipment. Refer to Section 3.3.2 for guidance on transportation of rental equipment.

C.2.1 Redundancy

N+1 equipment (or on-line sparing) is properly installed, connected equipment redundancy in a production, utility and/or support system. N+1 equipment ensures availability of the system to meet process demand in the event of an equipment breakdown. The equipment is available for use and can be put into full service to minimize the downtime and reduce the exposure from the breakdown of the equipment in service.

For N+1 equipment to be considered viable to minimize the equipment breakdown downtime and reduce the exposure, the following must be true:

A. N+1 equipment is properly installed, connected equipment redundancy in a production, utility and/or support system.

B. The redundant equipment can be put into full service with no discernable interruption to the process to reduce the business interruption exposure from the breakdown of the equipment in service.

C. The redundant equipment is not subject to damage resulting from deficiencies on the equipment in service.

D. The N+1 equipment design/rated capacity is compatible with the equipment in service and the process.

E. The N+1 equipment is inspected, tested, and maintained as part of the asset integrity program to maintain viability.

F. The N+1 equipment has been verified as fit for the intended service.

G. The N+1 equipment is available to be put into service in the event of a breakdown of the equipment in-service.

H. Standard/emergency operating procedures are in place to put the N+1 equipment into service and shutdown the in-service equipment.

The scope and implementation of the asset integrity program for N+1 equipment (on-line sparing) is the same program used for the equipment in-service to maintain spare viability.

Reducing the business interruption exposure from breakdown of the equipment in service is one of the key attributes of viable N+1 redundant equipment. To be able to reduce the exposure, the N+1 equipment is not subject to damage from deficiencies on the equipment in service.

Evaluate how the rated capacity of the redundant equipment compares to the equipment in service to determine to what extent the process can be restored in the event of a breakdown of the equipment in service.

Verify the availability and condition of redundant equipment as part of the asset integrity program. This includes any inspections required for the redundant equipment prior to start-up. Evaluate the fitness for the intended service of the redundant equipment. Consider if any repairs or alterations are required to make the redundant equipment usable.

Verify the procedures required are in place with appropriate level of training for switching the process from the original equipment in service to the redundant equipment. This includes shutting down the original in-service equipment.

C.2.2 Rental Equipment

Equipment rented/leased for use during a finite duration of time to supplement the existing facility.

1. Maintain supplier primary and emergency contact information.

2. Service agreements/contracts with OEM's and/or suppliers (including long term service agreements) concerning rental equipment availability and service).

3. Validate the scope and quality of the supplier's services.

4. Review rated capacity (output) of the rental equipment compared to the equipment in service.

5. Maintain installation, removal and dismantle specifications and requirements for the in-service and rental equipment.

   a. Identify the temporary connection points. The existing system should have adequate connection points to connect the expected rental equipment.

   b. Any commissioning process required by the rental should be documented and considered. In addition, any permits from local governments/utilities needed for the commissioning of a rental (e.g., environmental, electrical demand) should be identified and considered.

   c. Personnel required to remove the existing equipment and install the spare should be identified.

   - Identify any necessary vendors

   d. Any major modifications necessary for the spare to fit in the location designated for it should be identified and planned for (e.g., foundation, supports, frame sizes).

   - Ensure all hardware necessary to make the spare to fit is available (e.g. shim kits, couplings, cabling/bus bars, etc.).

6. Where vendors are required to perform any task associated with the implementation of the rental:

   a. Ensure they are pre-qualified to any potential OEM guidelines, and/or applicable codes and standards (e.g., RAGAGEP's). This includes any corporate standards and/or guidelines.

   b. Ensure they can provide any specialty labor/tooling requirements unique to the equipment.

APPENDIX D FOREIGN MATERIAL EXCLUSION (FME) PROCEDURE

D.1 Purpose

This procedure represents best-practice guidance to prevent foreign material from being introduced and left behind in pieces of equipment that are open for inspection, testing, maintenance, and/or repair and are susceptible to foreign object damage (FOD). The procedure also covers the control of items that are temporarily installed or used to facilitate work, such as tools, blank flanges, filters, orifices, and cleaning materials.

Note: The most efficient way to prevent foreign object damage (FOD) is to maintain high-quality housekeeping. Items cannot drop into a foreign material exclusion (FME)-controlled area if they are excluded from work areas to begin with. Proper tool management is needed to accomplish the required work activities. It is imperative that all personnel are aware of this policy and pay particular attention to all materials and tools that are brought into the work area.

D.2 Definitions

Access control: Methods used to control the entry and exit of personnel, tools, and materials. These include the use of boundary markers, signs, entry/exit logs, and monitors. Subject to the category of the foreign material exclusion (FME) areas, boundary markers should consist of solid barriers such as temporary metal walls, acrylic glass walls, wire fencing, or, if appropriate, fabric curtains, FME tape, rope, etc.

Access control point: A point established along a foreign material exclusion (FME) boundary at which entry of personnel, tools, and materials are permitted but controlled.

Clean area: A location outside of the FME area. It is typically a location set aside for sub-assemblies to be stored or to be worked on away from the FME area.

Close-out sheet: A close-out sheet is used to identify any discrepancies in the Foreign Material Exclusion (FME) Barrier Log (Form 2), FME Drop List (Form 3), Tool Log (Form 4), or Material Log (Form 5), as well as a description of any findings during close-out inspections, how the inspections were conducted (e.g., visual, borescope). Both the owner representative (OR) and the technical director (TD) should review and sign the sheet at completion of the outage or maintenance event. Completed close-out sheets should become a permanent part of the outage record.

Foreign material: Material that is not part of the system or component as designed, such as tape, tie-wire, tie-wraps, welding rods, tools, pens, pencils, electrical wire, cable, paper/plastic labels, stickers, signs, operations tags not properly secured, rags, plastic face shields, plastic bags, packaging, gasket material, excess sealant materials, ear plugs, sawdust, chemicals, solvents, paints, personal items such as eyeglasses or jewelry, or any other item that can affect the operation of the system or component.

FME audit: A periodic audit conducted by the owner’s representative (OR) and/or the technical director (TD) during a maintenance event using the FME Field Audit Checklist (Form 1) to evaluate the proper implementation of the FME program.

FMEA: Foreign material exclusion area; a work area around an open access, instrumentation, electrical, or mechanical component that should be surrounded by a physical boundary marker requiring specific controls to prevent the intrusion of unwanted material into a system or component. These areas should be posted.

FME barrier: A plug, cover, cap, bag, tape, netting, or other device used to close or cover an opening on a pipe or in a piece of equipment to prevent foreign material intrusion.

FMEA boundary: A physical boundary around a task, usually consisting of a boundary marker and visible signs identifying the specific area as a foreign material exclusion area (FMEA).

FME identification tag: Tags added to the end of lanyards, barriers or barricades in order to identify a specific FME barrier or boundary.

FMEA monitor: An individual responsible for access control in accordance with this procedure. The monitor is responsible for verifying all items logged by the work group, and should therefore be competent, well-trained, and fully aware of the consequences of foreign object damage (FOD) to the machine.

Lanyard: A strap, line, restraint wire, or similar used to secure an item in such a manner that it cannot become a foreign object in a foreign material exclusion (FME)-controlled area if the person holding or using it loses control of the item.

Owner’s representative (OR): The OR is responsible for overseeing the proper implementation of the foreign material exclusion (FME) program by the technical director (TD), and conducts periodic audits of the program in accordance with Foreign Material Exclusion (FME) Field Audit Checklist.

Technical director (TD): The supervisor (whether an employee of the owner or of the contractor performing the work) who has direct responsibility for overseeing the performance of the work being done on the equipment, and therefore direct responsibility for implementing the foreign material exclusion (FME) program during the outage.

D.3 Applicability

This procedure and all its provisions should be applied anytime a piece of equipment or system is opened for inspection, testing, maintenance, and/or repair. This includes, but is not necessarily limited to, turbines (gas or steam), generators, generator circuit breakers, transformers, piping systems, inlet air systems, condensers, heat exchangers, pumps, large motors, compressors, and other large stationary equipment. Given the varying levels of exposure to FME when performing inspection, testing, maintenance and/or repair work, different levels of application for the foreign material exclusion (FME) program are detailed below. Though there are different levels of FME recommendations, the general practices of FME should be adhered to during all inspection, testing, maintenance, and repair activities that expose the system. The overall risk involved with a potential FME event should be considered when choosing the level of protection to provide for the activity.

D.4 Responsibility

Everyone on the project should be fully versed in the program and understand the necessity of following the proper procedures. The owner's representative (OR) is responsible to ensure that all employees interfacing with the FME area receive a detailed introduction as to what is implemented, why things are implemented, and daily updates. The owner's representative (OR) is also responsible for overseeing the proper implementation of the foreign material exclusion (FME) procedure by the technical director (TD), through direct interaction with the TD and periodic audits of the program, as well as by routine spot checks for compliance.

The technical director (TD) should have primary responsibility and accountability for the implementation of the foreign material exclusion (FME) program on any project; The TD will also be responsible for obtaining concurrence at the start of each project with the owner's representative (OR) as to what inspection level will be required (e.g., visual vs. cameras) to prove that no foreign material has been left behind. It is imperative that the TD reinforce the FME procedure with all craft personnel during safety meetings.

All craft personnel, through coordination of the technical director (TD), are responsible for ensuring that FME barriers are in place and FME identification tags are hung and attached to particular openings, and that all such FME barriers and identification tags are properly entered on the appropriate form. Personnel should honor all foreign material exclusion (FME) tags, and no FME tags should be removed unless removal is connected with a work activity. If such FME tags are removed during the course of the work, they should be reinstalled unless component reassembly is imminent.

D.5 Foreign Material Exclusion (FME) Level 1

FME Level 1 applies to components and systems that have a low probability of foreign material intrusion and in which visual inspection and/or retrieval of foreign material is not impaired or restricted. In these cases, the difficulty of inspecting and/or retrieving items is low and requires no extensive disassembly of components. In general, the equipment involved in Level 1 is less vital and does not have critical tolerances related to it.

The minimum requirements for FME Level 1 are as follows:

A. Train all personnel on the requirements of the FME procedure, including contractor and owner's personnel, at the beginning of each outage. Include a signed acknowledgement by everyone that they understand the FME procedure (Form 6).

B. Take proper work precautions and use appropriate professional care.

C. Have a pre-job briefing describing all of the work to take place in order to properly prepare and only use the tools and material necessary. Follow appropriate work procedures. Update the briefing as needed

D. Locate FME boundaries and FME identification tags at all access points notifying personnel of FME requirements.

E. List all tools and equipment on a Foreign Material Exclusion (FME) Tool Log (Form 4) and ensure they are accounted for at the end of each shift, or at changeover between shifts, and not left in problematic areas. The tools in the FME area should be evaluated and consolidated where possible to limit the number of tools, and thus the potential for FME exposure, in the area.

F. All equipment parts, both in the foreign material exclusion area (FMEA) and outside the area, should be neatly laid up. Smaller parts should be bagged or boxed and labeled. Part lists should be maintained, including a part count if there is more than one identical part. All parts that need to be replaced should be recorded using a Foreign Material Exclusion (FME) Material Log (Form 5).

G. Prior to disassembly, clean the equipment to be worked on or opened to prevent foreign material from being introduced once the equipment is open.

H. Once the equipment is open, secure all areas that could be susceptible to foreign material using FME barriers (covers, blanks, bladders, or other appropriate barricades). Complete and maintain a FME Barrier Log (Form 2). Ensure FME barriers are easily recognizable so they will not be mistaken for a normal part of the equipment or system, or ordinary consumable items (FME barriers are typically bright red or orange). Document all FME barriers using a FME barriers have a unique tag identifier specifying the location and type of barrier (e.g., plug, magnetic strip). Ensure that all FME barriers that are not easily observable (e.g., oil drain lines, air extraction lines) include a tail that extends from the FME barrier to the outside of the equipment, with the FME identification tag at the end of the tail.

I. Any foreign materials (debris, tools, rags, etc.) found when opening the equipment should be registered and placed in a controlled access area to allow for investigation and assessment by technical personnel.

J. Maintain a Foreign Material Exclusion (FME) Drop List (Form 3) at all times, and ensure all personnel immediately report (without fear of reprisal) anything that has been dropped and cannot be immediately found or retrieved.

K. Document any dropped or unaccounted-for tools on a Foreign Material Exclusion (FME) Drop List and ensure they are recovered immediately, if possible.

L. If new parts are to be installed, inspect and clean them thoroughly before installation.

M. Prior to removing any FME barrier, clean the area around the FME barrier to remove debris and other objects to prevent foreign material from being introduced once the equipment is open.

N. During reassembly, clear each item on the Foreign Material Exclusion (FME) Drop List (Form 3). Clear the blanks and covers list at the appropriate time during the reassembly process (i.e., only remove blanks and clear the item from the list when that section of the system is ready to be reassembled). Thoroughly inspect all parts and sections of the system for foreign material. Any FME barriers that cannot be accounted for should be reviewed by the technical director (TD) and the owner’s representative (OR).

O. Thoroughly clean all encasements (preferably vacuumed, but blown with plant air if necessary) prior to final inspection.

P. Prior to reinstallation, have all small-bore piping and tubing blown out, and all large-bore piping swabbed, vacuumed, or blown out. Also, all barriers should be removed. Clear the FME Barrier Log (Form 2). Any FME barriers that cannot be accounted for should be reviewed by the technical director (TD) and the owner’s representative (OR).

Q. Prior to closure or reinstallation, have all cases, piping, openings and drains visually inspected (directly or remotely). Inspections should be performed and/or witnessed by the TD and the OR.

R. Prior to closing the equipment for the last time, ensure all items on the FME Drop List (Form 3) have been resolved. If all items have not been accounted for, then the TD and the OR should discuss the drop list and mutually agree as to the appropriate course of action.

D.6 Foreign Material Exclusion (FME) Level 2

FME Level 2 applies to components and systems in which there is a possibility of foreign material intrusion, and in which visual inspection and/or retrieval of foreign material is minimally impaired or restricted. Level 2 applies to jobs that involve turbines and other critical rotating equipment, such as pumps and motors, that have tight, critical clearances, as well as vessels and piping systems that feed such systems.

The minimum requirements for FME Level 2 are as follows:

A. Adhere to all the FME Level 1 requirements.

B. Limit access to the foreign material exclusion area (FMEA) to a single location.

C. A foreign material exclusion (FME) Monitor should be used to control access to the work area, and to inventory all materials going into and out of the work area. Access to the work area should be restricted when the FME Monitor is unavailable.

D. Have all removed piping capped or plugged on both ends and tagged with location and other pertinent identifiers.

E. Provide a personal effects storage locker or bin for personnel entering the FME area.

F. Ensure personnel entering the FME area have empty pockets. Allow only necessary items in the FME area; all personal items (e.g., cell phones, watches, jewelry, pens, knives, and wallets) should be left outside. Any loose objects (including jewelry) not needed to perform a specific task in the work area should be left with the FME Monitor or in the personal effects storage locker or bin.

G. Instruct all personnel to verify that their clothing and bottoms of their boots are clean and free of debris prior to entering the work area. Have the foreign material exclusion area (FMEA) monitor visually inspect the clothing and boots of all personnel entering the work area, especially during the reassembly process.

H. Slip-on safety boots or boot covers, without shoe laces, are preferred. If slip-on safety boots are not used, laces and buckles should be taped down.

I. Safety glasses should be on lanyards.

J. Ensure all tooling in the work area is organized neatly and accounted for on a personal level (i.e., each person tracks their own tools: "'take out what you take in"').

K. Tooling should be tied off if there is a potential that it could be dropped into an area from which it cannot easily be retrieved.

L. All parts in the work area should be neatly bagged or boxed and labeled.

M. FME logs should be cleared at the end of each shift or at shift change, with the exception of long-term tools.

N. The technical director (TD) should, on a regular basis but at least weekly, conduct an FME audit, including an audit of the FME boundary, FME Identification tags, FME barriers, foreign material exclusion area (FMEA) login/logout books, and an inspection of all piping that has not yet been installed. Audit should be performed in accordance with Foreign Material Exclusion (FME) Field Audit Checklist (Form 1).

O. The owner's representative (OR) should conduct an audit of the FME program at least weekly. Audit should be performed in accordance with Foreign Material Exclusion (FME) Field Audit Checklist (Form 1).

P. When performing remote visual inspection of hard-to-see areas, the TD and OR should decide ahead of time whether a recorded video or pictures will be filed with the outage report.

D.7 Foreign Material Exclusion (FME) Level 3

FME Level 3 applies to components and systems in which there is a possibility of foreign material intrusion, and in which the difficulty of inspecting and/or retrieving items is high, possibly requiring extensive disassembly of components. Level 3 applies to jobs that involve major disassembly of rotating equipment, specifically turbines and generators. The introduction of foreign material into these systems would most likely have devastating and costly effects.

The minimum requirements for FME Level 3 are as follows:

A. Adhere to all of the FME Level 1 and FME Level 2 requirements.

B. An access-control point should be established, and all personnel should be required to sign in and out of the area, providing a complete inventory of all items, including long-term and short-term tools and parts brought into the work area. Access to the work area should be restricted when the FME Monitor is unavailable.

C. An FMEA Monitor should be assigned to enforce access control and verify inventory into and out of the FMEA work area.

D. Ensure all tools, including flashlights, are on lanyards. All tools should be tied off on the personnel using the tools to prevent them from falling into the open equipment. All tools that may have battery or other compartments/attachments open should be taped at each compartment/attachment to prevent the compartment/attachment from opening (e.g. flashlight, air monitor).

E. When components or sub-assemblies are moved to a "clean area," apply the FME program to this area as well.

F. When working on electrical generators or large electric motors, do the following:

1. Ensure a supply of clean, warm, dry air to the generator to alleviate moisture ingress into the generator.

2. Provide an enclosure or cover (e.g., a tent or tarp) in addition to side barriers to protect against dust, moisture, birds roosting over the open equipment, etc.

3. Ensure all personnel working in the foreign material exclusion area (FMEA) have boot covers and lint-free overalls with no pockets.

Form 1. Foreign Material Exclusion (FME) Field Audit Checklist

Plant Site/Job:________ Date:________ Technical Director:________ Time:________

All tasks apply to all FME levels unless noted otherwise

	Task	*Yes*	*No*	*N/A*	*Comments*
1	Are FME boundaries established and marked?				
2	Is appropriate signage in place?				
3	Are FME barriers installed properly?				
4	Are FME tags attached to FME barriers?				
5	Are FME tags filled out properly?				
6	Are any FME barriers missing?				
7	Is the FME log filled out properly?				
8	Are supervisory personnel enforcing FME procedures?				
9	Is removed piping (including tubing) tagged and identified?				
10	Is the drop list up to date?				
11	How many items are on the drop list?				
12	Is the FMEA log book up to date?				
13	Is the FME monitor utilized? (Level 2 & 3)				
14	Is removed piping (including tubing) capped/covered on both ends? (Level 2 & 3)				
15	Is there a bin/locker for personal effects? (Level 2 & 3)				
16	Are all parts in the work area bagged, boxed, or labeled? (Level 2 & 3)				
17	Are FME logs cleared at the end on each shift? (Level 2 & 3)				
18	Is tooling organized neatly? (Level 2 & 3)				
19	Is the FMEA monitored checking to insure personal items are removed? (Level 2 & 3)				
20	Are all tools on landyards? (Level 3)				
21	Is generator/electrical FME policy in effect? (Level 3)				
22	Is generator/electrical equipment covered and supplied with heated and dried air? (Level 3)				
23	Are personnel wearing boot covers and lint-free coveralls in the generator area? (Level 3)				

Comments: ________

Completed by: ________ Owner's Representative: ________

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Form 2. Foreign Material Exclusion (FME) Barrier Log

Plant Site/Job:________________ Date:__________ Technical Director:________________

Tag #	*Install Date*	*Location*[1]	*Type of Barrier*[2]	*Installed By*	*Removed By*	*Removal Date*	*Inspected By*	*Signed*

[1] Where was FME barrier installed? (Bearing drain line, steam injection, extraction line, etc.)
[2] What type of FME barrier was used? (Plugs, magnetic strips, pipe caps, etc.)

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Form 3. Foreign Material Exclusion (FME) Drop List

Item	*Date Lost*	*Description*	*Where Lost*	*Date Retrieved*

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Form 4. Foreign Material Exclusion (FME) Tool Log

Tool Number	*Description*	*Date In FMEA*	*Date Out FMEA*	*Person's Name*

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Form 5. Foreign Material Exclusion (FME) Materials Log

Materials	*Description*	*Date In FMEA*	*Date Out FMEA*	*Person's Name*

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Form 6. Foreign Material Exclusion (FME) Acknowledgement Form

Plant Site/Job:—————————————————— Date:———————

Technical Director:——————————————————

By signing this form, I acknowledge that I have received the necessary training to understand the FME procedure being utilized on this job.

Name (print)	*Name (sign)*	*Date*

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APPENDIX E ALTERNATIVE SERVICE PROVIDERS

E.1 Guidelines for an Audit and Inspection Program for Alternative Service Provider (ASP) Services and Components

When equipment services and/or components are being (or have been) procured, a Client Audit and Inspection (A&I) Program should be in place to ensure that quality components and services are being procured.

For all services and components:

A. The service provider should have a documented and verifiable Quality Assurance and Quality Control (QA/QC) program that includes full traceability of all parts and materials.

B. The service provider should have a documented and verifiable QA/QC program that includes specifications, procurement, manufacturing, inventory, inspection, testing, transport, storage, installation checkout and commissioning as applicable to the services procured.

C. At a minimum this program should also address the items listed below as is appropriate for the service(s) or components being procured. This guidance should not be considered complete but rather as a starting point for the development of a detailed A&I Program.

D. The A&I should be put in place by the purchaser, or the party designated by the purchaser to procure the services and/or components.

E.2 Field and Shop Inspection Services

Inspection services provided may include several types of non-destructive examinations (NDE). When these services are being procured:

A. The inspector(s) should have relevant experience for both the type of inspection(s) being performed and of the specific component being inspected. In addition to this experience, ensure the inspector has access to the OEM's recommended inspection procedure (or equivalent) and the OEM's acceptance criteria.

B. If NDE services are being provided, the NDE technician should be certified to ASNT SNT-TC-1A, Level II at a minimum (or an equivalent nationally recognized standard).

C. ASNT SNT-TC-1A is a recommended practice that provides guidelines for employers to establish in house documented programs for certification of NDE personnel. This is not the same as an ASNT certification since companies can tailor their in-house certifications to meet their minimum needs.

D. Services should be provided in accordance with a qualified documented procedure or have appropriate traceability.

E. The service provider should adhere to a strict foreign material exclusion (FME) procedure (See Appendix D).

E.3 Field Services

Field services provided may include craft labor, technical field direction and NDE services. When these services are being procured:

A. The service provider should utilize appropriately skilled, trained, experienced, and documented engineers and technicians. NDE personnel should have the appropriate level of certification for the technique being applied.

B. The service provider should follow industry established good engineering practices, processes, and procedures. Services should be provided in accordance with a qualified documented procedure.

C. The service provider should adhere to a strict FME procedure.

D. The service provider should have (or have access to) appropriate shop fabrication capabilities. The shop should have documented quality control of critical equipment performance measures.

E. The service provider should have documented training records for all field servicing and installation personnel.

F. The service provider should have adequate support staff when issues arise that cannot be adequately answered in the field.

G. As appropriate, all tooling provided by the service provider should have been inspected and determined to be fit for service, with particular emphasis on lifting devices.

E.4 Shop Services

An important part of the inspection, testing and maintenance of equipment is the reconditioning of components to extend their service life. The reconditioning process may involve many disciplines such as skilled labor, destructive and non-destructive examination personnel, and engineering support. When parts are sent to a shop for reconditioning, ensure the following are in place:

A. The facility should have relevant experience for both the type of refurbishment being performed and on the specific component(s) being refurbished. In addition, any inspection services should comply with Section C.1.1 of this document.

B. The service provider should have a documented program in place so appropriately skilled, training and experienced personnel are utilized. The service provider should have documented training records for all reconditioning personnel. The service provider should follow industry established good engineering practices, processes, and procedures.

C. The service provider should have appropriate reconditioning capabilities (or an approved vendor), as well as documented quality control of critical component performance measures.

D. The service provider should have access to replacements for parts that are scrapped during the repair process. The service provider should verify the suitability (histories or pedigrees) of the replacement parts to be utilized for one or more service interval(s).

E. The service provider should have verified the source of all consumable materials used during the repair process, such as weld wire, filler materials, braze materials etc. Repairs such as brazing and/or welding should undergo an engineering evaluation. This includes metallurgical analysis to verify the repair method is adequate for the specific application, materials and temperatures using qualified procedures and certified welders.

F. The service provider should have an adequate and verifiable source for all miscellaneous hardware required during the repair process, such as pins, seals, etc.

G. The service provider should have documented, qualified repair procedures that produce repeatable quality to meet OEM specifications. The repair process should include detailed process specifications to perform the procedure steps:

1. Recording the component part number, serial number, accumulated operating history since the last repair and since original manufacture.
2. Incoming visual, dimensional, NDE and defect mapping/ photographs
3. Base material metallurgical analysis as required to verify material composition and properties
4. Disassembly of subassembly components
5. Cleaning
6. NDE methods to documented, qualified procedures
7. Heat treatment
8. Welding and brazing repairs to qualified procedures with certified filler materials based on compatibility with the base materials
9. Preheat and post weld stress relief heat treatment (where required)
10. Machining to match the required dimensions of the repaired component.
11. Recoating and diffusion heat treatment (where required)
12. Reassembly of subassembly components
13. Quality control/assurance inspections, final testing etc.

Once the first component is processed utilizing the applicable procedures and meets the quality requirements, the qualified repair procedures and process specifications are utilized to ensure repeatable quality. Any future improvements to the repair process and procedures should trigger a reevaluation of the qualification with changes documented in a management of change revision process. The revised process should be utilized where required for those specific conditions to ensure repeatable quality.

E.5 Aftermarket Components (Reverse Engineered and Reengineered)

Prior to utilizing aftermarket components, the supplier should have evaluated the OEM's component design and identified any issues with the parts performance (i.e., premature oxidation, cracking, wear, or failure). If no issues can be identified and there are no patent infringement issues, then a reverse engineered component that meets the quality criteria listed below is an acceptable alternative. If there are known issues with the component, then a reengineered component that meets the criteria listed below is acceptable.

E.5.1 Reverse Engineered Components

If a sample is provided by the Owner to be the basis from which the reverse engineered component will be modeled, the Owner should understand that the component may be damaged/destroyed for metallurgical analysis to accurately quantify the component. Six new parts is considered the minimum statistically significant quantity of parts to reverse engineer for component characteristic accuracy.

The sample/samples from which the reverse engineered component is to be measured should be dimensionally accurate and within appropriate tolerances. 3D Measurements should be performed using reproducible measuring techniques such as laser, white light, computerized tomography (CT) or X-ray scanning.

Identification and replication of all alloys used in the component, coating (where required) and subassembly components should be determined by spectrum analysis or an equivalent means. All necessary and appropriate metallurgical surface finishes should have been identified and incorporated.

Any deviations from OEM standards, such as alternate alloys or other materials, should be evaluated and determined to be acceptable prior to use in the design.

Appropriate expertise (either internal or external to the Owner) should be engaged to assist with developing metallurgical and other pertinent technical specifications for the purchase of the reverse engineered components.

E.5.2 Reengineered Components

When a component experiences consistent issues during operation (i.e., failures) an Alternative Service Provider should reengineer (redesign) the component to address these issue(s) before manufacturing the component. Another situation where an Alternative Service Provider may choose to reengineer a component is to avoid potential patent infringement issues.

E.5.3 Design Process

The supplier should analyze the potential root cause(s) of any issues with the component using equipment testing, lab testing, computer models, etc. as necessary.

Components with known issues should be redesigned to eliminate issues (utilizing state-of-the-art, generally accepted and up to date analytical tools, and testing).

The impact of the redesigned component(s) on other components and the overall engine performance should be evaluated as part of the redesign process. The supplier should have an established process with documented procedures that include all steps of the engineering design process.

The supplier should be willing to fully disclose, to the Owner and FM, the design rational and any assumptions utilized when reengineering or making modifications that could materially change existing equipment performance.

E.5.4 Validation/Testing Process

The supplier's validation process for their design changes should include verification of the resonant frequency margins.

The supplier should have testing capabilities to prove that the reengineered component(s) will perform as required for the service intended. A redesigned component, or group of components, should not materially impact the remaining portion of the equipment unless an analysis done for all the effected components conclusively shows that the affected components will not be adversely impacted under all operating conditions.

Redesigned components should undergo testing utilizing additional instrumentation as required to assist in the evaluation of the performance of the new design.

Additional periodic inspections should be performed until the component has proven that it is suitable for the operating environment and application within the equipment and meets the target repair and replacement interval.

E.5.5 Manufacturing Process

The component supplier should have a documented quality assurance/ quality control program which is available for review by the Owner.

The quality assurance/ quality control program should be explicit in how the parts supplier monitors and guarantees the quality of all work being provided by subcontractors of all tiers, including raw material suppliers.

The parts supplier should guarantee compliance with their material specifications and that all material certificates have complete traceability in accordance with the material identification program.

The parts supplier should provide critical manufacturing data to the Owner for review, such as master heat chemical analysis, high resolution radiographs, bond coat and top coat certification and analysis for all coatings being used (where required) and heat treatment documentation showing time at temperature.

E.6 Industrial Control System (ICS) Upgrades/Replacements

The ICS should provide complete, reliable, state of the art, control, monitoring, sequencing, and emergency protection functions for the equipment.

The service provider should follow industry established good engineering practices, processes, and procedures.

The service provider should have detailed knowledge of the specific equipment model and configuration being controlled.

The service provider should be knowledgeable of the strengths and weaknesses of the controls platform being utilized, including response rate and sample rate. The service provider should be able to articulate how the offered controls platform compares to the system being replaced and be able to address any perceived relative weaknesses of the new system.

The service provider should understand the known failure modes of the control's hardware being offered and should be able to address how these failure modes can manifest and how to protect against them.

The ICS should incorporate all equipment OEM recommended protection systems.

Sufficient redundancy should be provided in the protection systems such that no single failure will cause an equipment trip or prevent the equipment from being tripped.

System diagnostics should be provided as an integral part of the ICS. Automatic recognition and location of instrumentation and control faults should be available at the engineering and operator's workstations. Fault alarms should be available for each device fault.

The new/modified system should provide the capability to test the protection systems. If the proposed systems are ″self-diagnostic″ to the extent that separate testing is not considered to be necessary, the supplier should provide documentation verifying that the ″self-diagnostic″ features are sufficient to eliminate the need to separately test the components of the system.

Comprehensive Factory Acceptance Testing (including critical auxiliary systems) should be done as a part of the commissioning process to ensure the system works as intended. The hardware should be physically tested to ensure it is functioning properly.

Comprehensive Site Acceptance Testing (including critical auxiliary systems) should be done as a part of the commissioning plan to ensure the system works as intended.

E.7 Alternative Service Provider (ASP) Service Agreement

A service agreement is an agreement to supply some combination of replacement parts, parts refurbishment, inspection services, field services, monitoring & diagnostics (M&D), inventory management and contract management. When entering into a service agreement type contract with an Alternative Service Provider, all the applicable considerations presented in this Audit and Inspection section of the Data Sheet should be considered.

A financial and technical due diligence should be performed on any ASP service agreement service provider under consideration. This due diligence should include any sub-suppliers that will be furnishing parts or services under the service agreement.

In the case of a forced outage, the supplier should be able to provide parts and services in a timely manner.

The Owner should reserve the right to source parts and services from the OEM or other sources if the ASP(s) cannot perform in accordance with the contract.

If the service agreement service provider is sourcing new alternative service provider parts and is not controlling the manufacturing process directly, the service agreement contractor should have a program in place to guarantee parts quality and adherence to the guidelines presented in these A&I program guidelines.

If the service agreement contractor is going to supply refurbished, grey market or used components into a pooling arrangement, the supplier should guarantee parts pedigree, (i.e., the operating history since new and since the last repair, as well as other key historical parameters), to ensure that the parts are fit for the intended service of the equipment.

The Owner should maintain the right to utilize the services of third- party contractors/consultants to support outage oversight; parts refurbishment processes or in the event of a failure, a root cause analysis (RCA).