Asset Integrity – Process Safety Management (Techniques and Technologies)

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ABSTRACT

This paper discuses concepts and methodologies to Asset Integrity and Process Safety Management (AI-PSM) of Hydrocarbon Operations and elaborates on Inherently Safe Design as a predictive method to meet Process Safety requirements early at the Design Stage.

Technologies to aid in AI-PSM, including Focused Asset Integrity Review, monitor performance and manage the integrity barriers will also be discussed in this paper.

Keywords: Technical Integrity, Asset Integrity, Inherently Safe Design, Process Safety, Technical Integrity Barriers, Safety Critical Elements, Technical Integrity Review.

INTRODUCTION

Hydrocarbon Operations are hazardous in nature, whereby potential or likelihood of leaks and releases causing damage to life, property, environment and/or Operators' reputation vary depending on the Technical Integrity measures taken to ensure that assets are being designed, operated, inspected and maintained in a way such that under normal operating conditions, the risks are tolerable and controlled at an "As Low As Reasonably Practicable (ALARP)" limit.

Since the Technical Integrity measures (whatever comprehensive) cannot grant the achievement of the "Zero Accident" goal, major hydrocarbon operators are prepared with Emergency Response Plans that address initial response and communications leading to the containment of major accidents and associated escalation of events (e.g. H2S release, Hydrocarbon/Chemical Spill, Fire and Explosion, Radioactivity), consequently safeguarding of lives, the environment, and asset value/revenue.

TECHNICAL INTEGRITY

By definition, Technical Integrity (TI) of an asset is achieved when: under specified operating conditions, the risk of failure that endangers the safety of personnel, the environment, asset value, or Company reputation is tolerable and has been controlled or contained to be ALARP.

TI (as practiced by major operator; as advised by global regulatory bodies) depends on controlling the escalation of emergency events and associated consequences at ALARP level, by forming a successive set of Integrity Barriers that run from safe operating mode to escalation, i.e. Structural Integrity, Process Containment, Ignition Control, Detection System, Protection System, Shutdown System, Emergency Response, and Lifesaving, where each barrier contains a group of Safety Critical Elements (SCEs).

For each SCE, Performance Standard with specific functional goals, acceptance criteria, and minimum assurance tasks are used to determine whether the TI for that SCE is demonstrated, or else, gap closure recommendation is specified to retain the ALARP status.

INTEGRITY BARRIERS AND SAFETY CRITICAL ELEMENTS

SCEs are defined as those items of equipment or structures whose failure could lead to a Major Accident or whose purpose is to prevent or limit the consequences of a Major Accident. In Figure 1 (below), reference was made to the Integrity Barrier “Swiss Cheese” Model of Shell EP.

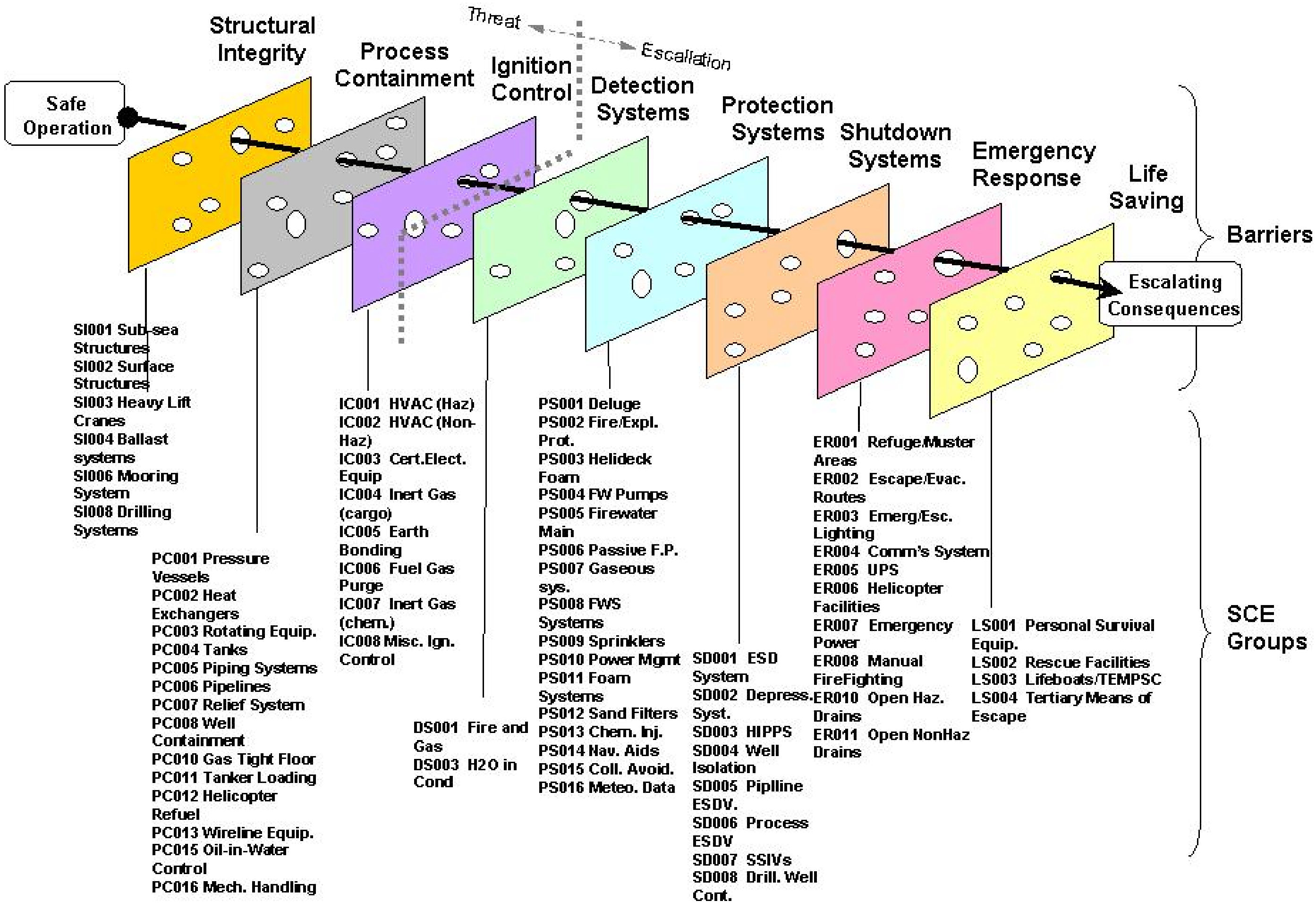

Figure 1 - Integrity Barrier “Swiss Cheese” Model of Shell EP

TECHNICAL INTEGRITY FRAMEWORK

Asset Integrity has always been subject to deterioration over time for a number of reasons, e.g. faulty design, wrong selection of materials, improper operation, and maintenance (leave aside the aging and end of service considerations). Therefore, a proactive mechanism to assure the TI of an asset can ideally be made to maintain its fitness for purpose throughout its whole life cycle (from design to decommissioning).

The integrity assurance framework, accordingly, is extended from the design stage (during which, Engineering defines Integrity Standards and Design Envelops based on Operational Safety Cases to assure the Design Integrity) until post-handover of assets to Operations, where Engineering provide Operations with Operating Envelops, Inspection and Maintenance guides to safeguard the Technical Integrity of the assets (or what is called Operational Integrity assurance practices that are aimed at sustainable operations of the assets at the Design Standards).

ASSET INTEGRITY AND PROCESS SAFETY (AI-PS)

Asset Integrity and Process Safety (AI-PS) of hydrocarbon facilities are intrinsically linked and together they constitute TI, where Asset Integrity is the process of establishing TI, by understanding and evaluating key risks early at the design stage, selecting protection, and defining controls to contain risks of failure at ALARP limit. In simple trams, Asset Integrity is the efforts aimed at designing for safety and environmental integrity to proactively meet the Process Safety requirements.

Process Safety, in turn, is the efforts of safeguarding Asset Integrity through, verifying that appropriate assurance measures are in place to oversee operating assets and timely intervene to safeguard their performance within design standards. In other words, Process Safety depends on structuring robust controls to manage technical risks by maintaining the TI of the SCE to sustain the ALARP status throughout asset lifecycle.

Since AI-PS goal is the fitness of the assets throughout their lifecycle (from design to decommissioning), aligning TI measures with an efficient and cost effective Maintenance Program (ideally based on Risk-Focused Maintenance methodology) is a must. Figure 2 illustrates the Asset Integrity – Process Safety management process.

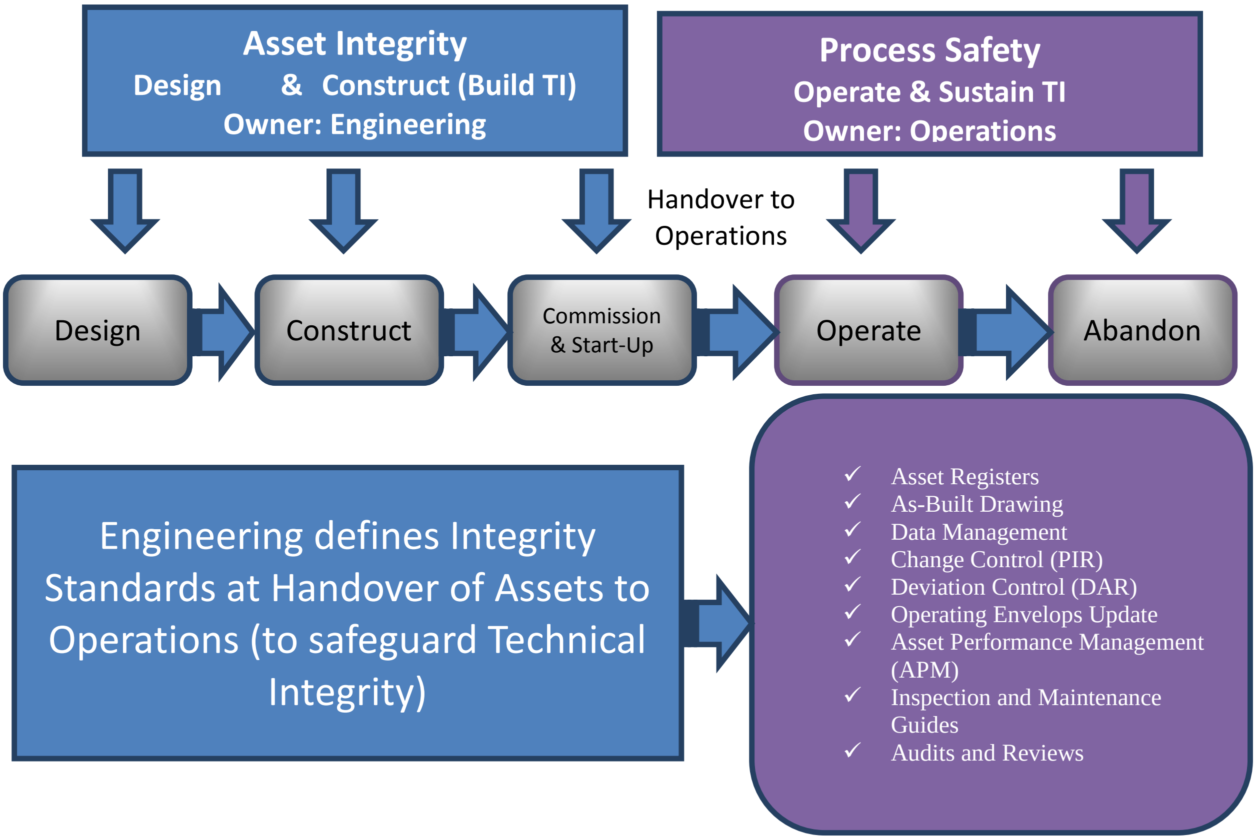

Figure 2 –AI-PS Management Process

AI-PS and RISK ANALYSIS RELATIONSHIP

Asset Integrity and Process Safety (AI-PS) of hydrocarbon facilities are intrinsically linked. They are (fundamentally) the processes of understanding key risks early at the design stage, accordingly:

evaluate, select, define, and execute the design for safety and environmental integrity based on ALARP and Inherent Safety concepts, then sustaining the operation within these design measures throughout the asset service period. This task requires a comprehensive risk analysis and risk control capabilities.

DEFINITIONS of RISK and PROBABILITY

Western Canadian Spill Services Limited defines **Risk** as: “The measure of the probability and severity of an adverse effect to health, property, or the environment”. However, most of major Operators add adverse effect to their reputation as a risk assessment factor.

Probability is the likelihood of an event occurring during an interval of time. **Risk** is often estimated by the mathematical expectation of the consequence of an adverse event occurring (i.e., the product of "consequence").

RISK ASSESSMENT

A risk assessment is all about careful examination and calculation of potential hazards that could result in harm to people, asset, environment, or company reputation. A typical risk assessment process may include the following steps:

- Identify the hazard (defined as any situation that has the potential to cause harm to people, asset, environment, or company reputation);
- Determine the risk (using the product of "probability x consequence" formula);
- Evaluate the risk, and then decide whether the existing precautions/controls are adequate, or whether more control measures are still needed;
- Keep record of your findings, and maintain weighing them against the risk control measures in place and the control measures that are required by the regulatory bodies;
- Based on the above, implement your control strategies;
- Following the implementation of control strategies, keep revising risk, control strategies and make changes as necessary; and
- Conduct a new risk assessment following any significant changes or an incident.

Risk levels based on probability and consequences may be better assessed by using the following formula: Risk = Consequence (severity of impact from an event) X Probability (likelihood of event occurring), as represented in the following Risk Assessment Matrix (Table 1).

Hazards					Probability (Likelihood of event occurring)				
People	Environment	Asset	Reputation	Severity of Consequences Severity of Consequences	Has happened more than once per year at the Location (5)	Has happened at the Location or more than once per year in Company (4)	Has happened in the Company or more than once per year in the industry (3)	Heard of in E&P industry (2)	Never heard of in E&P industry (1)
More than 3 Fatalities	Catastrophic damage >US$ 10M	Catastrophic effect	Catastrophic impact	Catastrophic (5)	25	20	15	10	5
PTD or up to 3 fatality	Major damage <US$10M	Major effect	Major impact	Major (4)	20	16	12	8	4
Major injury	Moderate	Moderate	Moderate	Moderate	15	12	9	6	3

or health effect	damage < US$ 1M	effect	impact	(3)	🟥	🟥	🟨	🟨	🟩
Minor injury or health effect	Minor damage <US $100K	Minor effect	Minor impact	Minor (2)	10	8	6	4	2
Insignificant Injury/health effect	Insignificant damage <US $10K	Insignificant effect	Insignificant impact	Insignificant (1)	5	4	3	2	1
No injury or health effect	No damage	No effect	No impact	No impact (0)	0	0	0	0	0

Table 1 – Risk Assessment Matrix

TI COMPLIANCE AND TOLERANCE COLOR-CODE

The Risk Assessment Matrix (Table 1) and associated Color-code can be used to determine the Criticality Level of a SCE, and to determine its Current Status in terms of compliance with TI standards as follows:

🟥 Red, used when Technical Integrity is NOT demonstrated;
🟨 Yellow, used when Technical Integrity is demonstrated, but areas of improvements are identified; and
🟩 Green, used when Technical Integrity is demonstrated; no further action is required.

Likewise, Assessment Matrix Color-code can be used to express the tolerance and assist in setting response priorities as follows:

🟥 Red, requires immediate risk control action(s);
🟨 Yellow, requires further evaluation to determine if existing controls are sufficient, or else, corrective action is needed; and
🟩 Green; risk is tolerable/no risk control action is needed.

TECHNICAL INTEGRITY ASSESSMENT

Technical Integrity assurance involves assessment of the following:

- Technical Integrity of Upstream and Downstream Facilities (Wells, Pipelines and Facilities/Process Equipment);
- Roles, Responsibilities and associated Competence System;
- Document Control System;
- Data Management System;
- Management of Change;
- Performance Monitoring and Measurement;
- Inspection and Maintenance Processes;
- Reliability/Key Performance Indicators; and
- Technical Assurance and Verification Mechanism.

TI ASSESSMENT METHODOLOGY

As explained earlier, TI assurance depends on risk assessment and risk controls to contain the escalation of consequences at ALARP level. To achieve this goal, Integrity Barriers with Safety Critical Elements have been introduced, and periodic inspection is required to assess the current status of the SCEs against TI measures that include functional goals, performance criteria, and minimum assurance standards for each SCE.

Response action and timeframe depends on the SCE criticality level. The assessment can possibly be conducted either manually or automatically (using a software tool).

FAIR Methodology & Technologies

As part of Shell AI-PS Management System that drives to assess and improve the Technical Integrity status of the exploration and production facilities, a Global Technical Integrity Review and Improvement Program was initiated in 2006, where Shell Global Solutions International's (Shell GSI) leading teams of regional discipline engineers have developed two software tools to aid what they call "Focused Asset Integrity Review (FAIR)".

The objective of the two FAIR versions (as explained later in this paper) is to help exploration and production operations comprehensively understand the operational risks, then identify and implement controls/improvements to the Technical Integrity Management System as a whole (Technical Integrity of the assets and the system alike; from well bore to point of hydrocarbon sale.). Note that Shell's FAIR and AI-PS Management System depends only on "Hardware Barriers" [physical assets]. Software Barriers (knowledge and skills) are addressed in their "Corporate Management System".

a. FAIR^{+}ER

The first FAIR software tool to be introduced is the 'Equipment Review' ("FAIR+ER"), which aids the assessment of the current status of equipment. FAIR+ER methodology comprises a detailed review of the present condition of an equipment to determine if it performs it function as per design when called upon, and if it is in compliance with the functional goals, performance criteria, and minimum TI assurance standards that have been predefined for each equipment (SCE).

FAIR+ER employs experienced discipline engineers (usually supervised by "Technical Authorities (TAs)") to review equipment history and condition records, and then conduct site interviews to capture findings, collect evidences, discuss concerns and get suggestions from asset personnel with roles to maintain the asset integrity, including reliability, inspection, operation, and maintenance teams.

FAIR+ER discipline engineers record their findings along with references to evidences and other information gathered during the review on Current Status Reports (CSRs) that the FAIR+ER software produce for each SCE. Each CSR gives a conclusion about the Technical Integrity status of the relevant SCE by means of outlining the acceptance criteria for the relevant SCE with check boxes to ease consistent conclusion of the current integrity status. Typical conclusions are either: 1) Technical Integrity is NOT demonstrated; 2) Technical Integrity is demonstrated but areas of improvement identified; or 3) Technical Integrity is demonstrated.

CSRs include a risk assessment matrix to define a priority for the recommendation, and another set of checklists with guidance to evidences and typical questionnaire to facilitate site interviews and to maintain consistency. When all SCEs relevant to an integrity barrier have been assessed, the integrity status of this barrier can be determined; accordingly, recommendations to restoring design standards and/or improving integrity status can outlined on the CSRs. Operating units can then establish an implementation plan, an audit tracking mechanism to measure the progress and closeout completed tasks (to ensure compliance with TI teams' recommendations).

b. FAIR$^+$SR

FAIR+SR is the second software tool version produced by Shell GSI; it is a structured review of the Asset Integrity (as a Management Systems). FAIR+SR objective is to aid the control of activities, practices and procedures required to monitor, assess, improve and sustain the integrity of specific asset types and facilities, such as static equipment (e.g. heat exchangers, vessels and piping), instrumentation, rotating equipment, wells, pipelines and offshore structures. According to Offshore Technology, FAIR+SR "aspects of management systems reviewed are detailed as follow:

- Organization and Administration
- Skill Resources, Training and Certification
- Procedure and Practices
- Quality Assurance and Quality Control
- Maintenance Plans
- Module-Specific Aspects
- Corrosion Prevention and Control
- Inspection and Fitness For Purpose Assessments
- Testing Programs
- Data, Integrity Records, Tools and References".

FAIR+SR process begins with a preliminary self-assessment performed by local staff from the concerned operating unit using FAIR software, which provides them with guidance to the effectiveness of their TI Management System through answering a thorough series of questions about all aspects of the asset integrity systems applied at their location.

Status of an integrity barrier can be determined after the assessment of all SCEs relevant to that integrity barrier, then, the FAIR+SR team carries out a review of record systems and procedures through site interviews with a selected technical and operating staff from all disciplines and associated levels and functions.

Using the FAIR+SR software, the review teams analyzes the information gathered and conclude current status assessment on the management systems based on a gap analysis between the site self-assessment and the FAIR+MS team findings, accordingly, key findings, areas of strengths and weaknesses can be jointly introduced, leading to a prioritized list of improvement opportunities to the existing management systems.

TI DATA MANAGEMENT

Data management is a crucial task for the efficiency and viability of a Technical Integrity Management System. The data management begins at the early design stage, where the below listed data must be available prior to the commissioning of the asset and subsequently maintained up-to-date after project hand-over to operations and until abandonment of the assets:

- Design data (Including Design Envelope);
- Asset registers (into SAP or other CMMS);
- As-built-drawings;
- Inspection and maintenance plans and intervals (CMMS);
- Operating Manuals;
- SCEs;
- SCE Functional Goals and Acceptance Criteria (Performance Standards);

- MoC (Design Alteration and Plant Improvement Requests’ control process that runs through five steps: Screen → Review → Approve → Implement → Close-out);
- Maintenance history;
- Inspection/Audit findings and recommendations; and
- Inspection/Audit track records.

INTEGRATION OF TI WITH RELIABILITY, INSPECTION AND MAINTENANCE

Reliability programs can be utilized to measure the TI, where KPIs can be produced to rate the integrity of SCE against performance standards. Reliability programs can also help take overall Asset Performance (hardware) to the next level by focusing on optimum, efficient, and cost-effective performance of assets, people, systems and processes within the Technical Integrity as complementary framework.

TIF provides directions and guidance to align Technical Integrity (TI) practices with inspection and maintenance execution. The aim is to ensure that the scheduled Inspection and Maintenance programs are formulated by responsible/authorized personnel from technical, operational and planning disciplines and in compliance with the methodology, strategy and objectives that are globally adopted for the Asset Inspection & Maintenance Systems.

Inspection and Maintenance System should be directed to maintain the integrity of SCEs based on the following considerations:

- To ensure a continuous comprehension of the running condition of all SCEs;
- To direct the maintenance program so as to keep all SCEs in a satisfactory ALARP safe-state (from integrity, operability, and maintainability standpoint);
- To ensure the safe conduct of all inspection and maintenance tasks on SCEs;
- To direct the scheduling of the SCEs equipment towards efficient and cost effective ‘Productive Utilization of Assets’ by means of proper balance between SCEs running hours, inspection and shutdown maintenance (to maximize the MTBF and to minimize the MTTR simultaneously);
- To optimize the performance ratings of the SCEs;
- To ensure accurate and complete recording of SCEs inspection and maintenance activities, findings and service/corrective actions histories; and
- To maintain updated dashboards, KPIs, Management of Change, historical equipment inspection and maintenance records.

RISK-FOCUSES MAINTENANCE (RFM)

RFM is a technique for establishing a Reliability-Centered Maintenance (RCM) program. The RFM process is to focus maintenance resources only on components that enable plants to fulfill their essential functions when called upon, and/or to focus on components, which failure may initiate challenges to safety systems, so as to realize the greatest beneficial impact in reducing risk. In other words, RFM addresses the maintenance of TI Barriers and associated SCEs.

RFM process addresses only a portion of the RCM, which in turn addresses all portions or selected portion(s) of total plant maintenance program. Therefore, use of the RFM process should not preclude other maintenance activities.

RFM METHODOLOGY

RFM method consists of two major steps: 1) Identifying SCEs, and 2) Determining what maintenance activities are required to ensure reliable operation of the SCEs identified [2]. For TI purposes, the SCEs are identified through Hazard and Effect Management Process, in association with eight TIB as illustrated in Figure 1. Figure 3 illustrates the top-level RFM process.

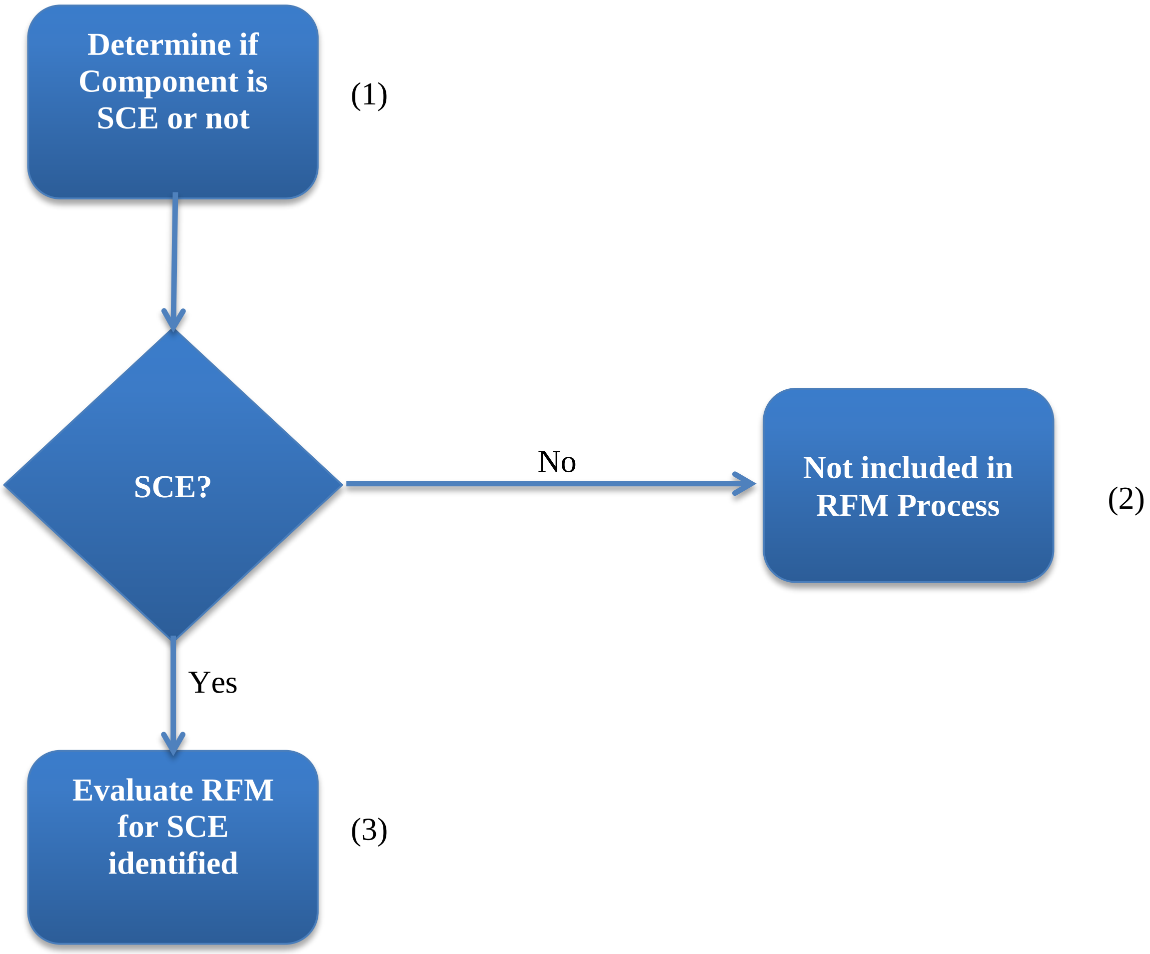

Fig.3 Top-level RFM Process

After identification of SCEs, a single approach of two steps is used to establish an RFM program. The first step is to determine the dominant component failure modes that should be prevented. The second step is to determine maintenance activities that will prevent the occurrence of those dominant failure modes. Figure 4 illustrates the maintenance evaluation for SCEs.

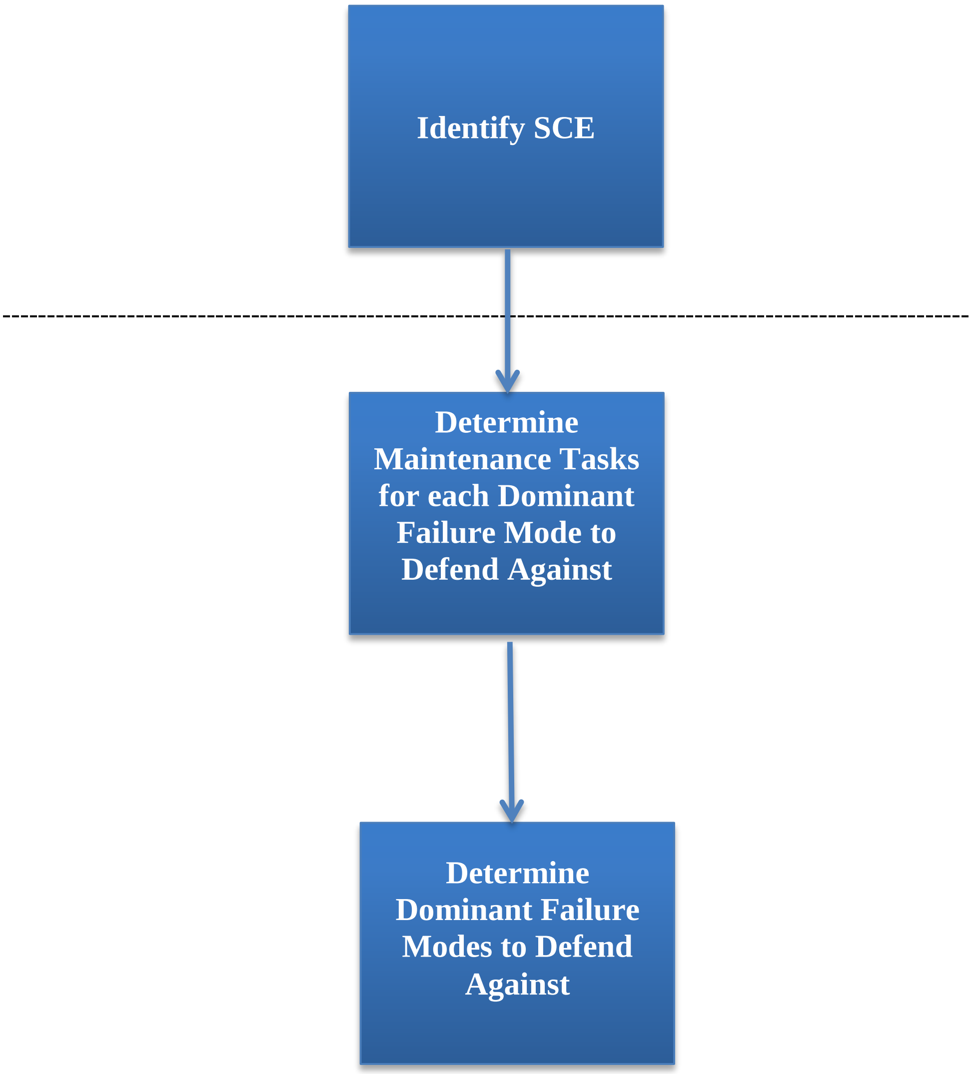

Fig.4 Maintenance Evaluation for SCEs

CONDITION MONITORING

An Effective RFM program requires operating the plant equipment under the watchful eyes of operation and maintenance teams, therefore, Condition Monitoring (CM) is an essential element that allows RFM to be proactive rather than reactive.

CM is the practice of “using the proper instruments” [3] (either hand-held or integrated with a PLC, DCS, or SCADA system) to monitor equipment/process variables, e.g. vibration, thermography, emission, releases, corrosion rate, NORM, and noise levels as a preliminary step. Comprehensive diagnostics of these variables and thorough understanding of safe operating limits are the key competence factors that allow TI/RFM engineers to timely interfere to restore the process safety. A separate research paper to discuss plant operations with safe parameters is currently being developed by the Author.

RESULTS AND CONCLUSIONS

Technical Integrity Framework comprises Asset Integrity and Process Safety assurance methodologies were presented. FAIR was also introduced as an state-of-the-art technology to aid in TI assurance.

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