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STEEL CATENARY RISER INTEGRITY MANAGEMENT

SCRIM

JOINT INDUSTRY PROJECT

# Summary of JIP

**Prepared for**

MMS

**U.S. Minerals Management Service (MMS)**

Reference No. 4-4-5-010/TN08

Rev. 1

**April 2008**

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# EXECUTIVE SUMMARY

The *SCRIM (Steel Catenary Riser Integrity Management) Joint Industry Project* was an industry-sponsored initiative, managed and delivered by MCS, to develop industry guidelines for the integrity management of offshore risers. The original scope of the JIP was to develop industry guidelines for the integrity management of steel catenary risers, but wide industry participation and funding well over the initial target allowed the JIP to extend its work into the integrity management of hybrid and top-tensioned riser systems.

The JIP was launched in October 2004. The project has been sponsored by 20 participants, comprised of operators, regulators, contractors, equipment vendors, pipe mills and transportation companies.

This document presents a summary of the JIP as of March 2008. The scope of the JIP consisted of several subtasks:

(i) Develop a systematic, risk-based approach to the integrity management of SCR field systems;
(ii) Provide a framework for structured record-keeping to allow periodic demonstration of fitness for purpose and/or to justify extension of service life;
(iii) Survey of SCR and component potential failure modes;
(iv) Identify current best technology, emerging technologies, and technology gaps relating to for SCR inspection and monitoring;
(v) Develop worked examples of methodology;
(vi) Provide a forum among JIP participants for informally sharing experiences in SCR integrity and design technology;
(vii) Develop industry guidelines on SCR integrity management.

The methodology produced by the JIP is consistent with the approach and requirements of the of the new API 2RD / ISO13628-7 (draft) Code of Practice for Dynamic Risers for Floating Production Installations and the new US CFR 250 Part J (Draft, Oct 2007).

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# GLOSSARY

For the purposes of this report the following definitions shall apply:

**Anomaly**

Any unacceptable monitoring or inspection result, or observation. Anomalies may occur at any phase of field development, and always require ad-hoc engineering assessment of their significance to risk.

**Consequence**

Detrimental effect of a failure in terms of safety, environmental, and/or economical impact.

**Consequence Index (C)**

Rating which denotes the consequence of a given failure mode, accounting for the safety, environmental and operational consequences of a failure mode occurring. Typically, the rating is an integer between 1 and 5. A high rating (5) represents the most adverse consequences.

**Cathodic Protection (CP)**

An electrochemical corrosion control method whereby the metal to be protected against corrosion is made the cathode for a galvanic corrosion mechanism. The dissolution reaction is transferred to an anode which may be a galvanic anode or an impressed current.

**Defect**

An anomaly attributable to material, manufacture, installation or operational conditions outside of specification or design conditions. A defect does not necessarily lead to consequences.

**Design pressure**

The maximum (or minimum) pressure, inclusive of operating pressure, surge pressure including shut-in pressure, vacuum conditions and static pressure head.

**Failure**

Loss of structural fitness for purpose of the pipe system. In practice failure constitutes a loss of ability to transport product safely and effectively. This may be catastrophic (the pipe ruptures or breaks) or may constitute a minor uncontrolled loss of pipe integrity or pipe. A failure is an unacceptable extent of a defect, which always has consequences.

**Failure Driver**

Convenient classification under which several possible modes of failure may be grouped together (e.g. fatigue, installation, accidental damage). Such groups facilitate the systematic identification of failure modes that can occur from specific sources.

**Failure Initiator (Root Cause)**

An event or process associated with the design, manufacture, installation, operation or maintenance, which initiates the failure mechanism associated with a given failure mode.

**Failure Mechanism**

The sequence of progressive stages from the initiation of a pipe failure mode (i.e. *Failure Initiator*) to the ultimate structural failure of the pipe (i.e. rupture, collapse, leakage).

**Failure Mode**

The unique combination of a failure initiator and a mechanism leading to pipe failure. All SCR failure modes culminate either in rupture, collapse or leakage of the riser.

**Hazard**

Dangerous conditions that can lead to negative safety, environmental and financial consequences.

**Hybrid Riser**

A riser is the fluid conduit between static pipeline on the seabed and hull pipe-work on the floating facility. The fluid conduit components of a hybrid riser, typically include the following components; metallic rigid pipe, goosenecks, flexible jumpers, subsea jumper/spool.

**Hybrid Riser System**

A hybrid riser system consists of a free-standing vertical riser section located below the dynamic wave zone, with flexible connections (jumpers) near the surface, between the vertical riser section and the vessel. The purpose of the flexible jumpers is to decouple the motion of the vertical riser section from the motion of the vessel. The vertical free standing riser section is typically maintained upright as result of buoyancy along the riser and/or a large buoyancy tank located at the top of the riser. The hybrid riser system is the combination of the riser(s) itself, all of its ancillary components and any other structure or attached components upon whose integrity, the integrity of the hybrid riser depends (e.g. buoyancy tank, core pipe, distributed buoyancy, anchor, riser bottom connection, flexible joints, metallic tapered stress joints, chains, CP anodes, coatings, strakes or fairings, insulation etc.)

**Hydrogen Embrittlement**

A process resulting in a decrease of the toughness or ductility of a metal due to the presence of atomic hydrogen in the metal.

**Probability Index (P)**

A rating representing the best estimate of the likelihood of occurrence of a failure mode. Typically, the rating is an integer between 1 and 5, with 5 corresponding to the highest likelihood of occurrence.

**Service life**

The period of time during which the SCR fulfils all performance requirements.

**Riser (or Dynamic Riser)**

Generic term representing production, injection, lift, or export risers, in dynamic service. A riser is the fluid conduit between static pipeline on the seabed and hull pipe-work on the floating facility.

**Stress Corrosion Cracking (SCC)**

Stress corrosion cracking is a cracking process that requires the simultaneous action of a corrodent and sustained tensile stress.

**SCR**

All dynamic and static steel catenary riser (SCR) sections including the end termination components of the riser. An SCR is the fluid conduit between static pipeline on the seabed and hull pipe-work on a facility.

**SCR System**

An SCR system is the combination of the SCR itself, all of its ancillary components and any other structure or attached components upon whose integrity the integrity of the SCR depends. The SCR system includes, in addition to SCR pipe, all ancillary components (e.g. coatings, porch, receptacle, dynamically loaded I-tubes, flexible joints, metallic tapered stress joints, mechanical couplings, seabed holdback anchors, CP anodes, holdback tethers, strakes or fairings, distributed or other buoyancy, insulation)

**TTR**

All dynamic and static top-tension riser (TTR) pipe sections from the seabed to hull pipe-work on the floating facility, typically including the following components: production tubing, inner casing, external casing, specialty joints, and surface equipment.

**TTR System**

A TTR system consists of a vertical riser section, with flexible connections (jumpers) between the vertical riser section and the vessel. The vertical riser section is typically maintained upright as result of either a buoyancy or mechanical tensioning system. The hybrid riser system is the combination of the riser itself, all of its ancillary components and any other structure or attached components upon whose integrity, the integrity of the hybrid riser depends (e.g. tensioning system, hydraulic tieback connector, flexible joints, metallic tapered stress joints, padeyes, CP anodes, coatings, strakes or fairings, insulation etc.)

**Vortex Induced Motions (VIM)**

Motions caused by oscillatory forces generated by vortices formed from surface currents interacting with a floating facility.

**Visual Examination**

Examination by eye, of parts and equipment for visible defects in material and workmanship.

**Vortex Induced Vibrations (VIV)**

Vibration of a riser caused by oscillatory nature of vortices released due to the interaction of the current and riser.

# 1 INTRODUCTION

## 1.1 BACKGROUND FOR JIP

The SCRIM JIP was launched by MCS in October 2004 to develop a systematic, risk-based approach to the integrity management of SCR field systems.

At the launch of the JIP, no widely-accepted systematic approach had been developed for the assessment of risk for steel catenary riser (SCR) systems and the development of appropriate integrity management strategy based on that risk. Risk-based integrity management of SCRs has lagged behind such approaches developed for other safety-critical assets like pipelines and flexible risers.

The increased use of SCRs, especially for production risers, together with failures of some SCR components provided increased incentive for ensuring that systematic integrity management programs, combined with effective monitoring and inspection methods, exist that are capable of prevention or early detection of integrity problems with such systems.

With additional participation and funding over the originally planned JIP scope, the IM methodology developed by the JIP was extended to include both hybrid riser and top-tension riser (TTR) systems. A consistent methodology is presented for addressing these riser systems.

## 1.2 PARTICIPANTS

The project has been sponsored by 20 participants as of September 2007; it has comprised of operators, regulators, contractors, equipment vendors, pipe mills and transportation companies.

- Operators
  - Anadarko
  - BHP Billiton
  - BP
  - Chevron
  - Dominion (ENI)
  - ExxonMobil
  - Kerr Mc Gee
  - Shell
  - Petrobras
- Transportation Companies
  - Enterprise Products Partners
  - Williams
- Contractors and Manufacturers
  - Acergy
  - SBM-Imodco
- Manufacturers
  - Oil States Industries
  - RTI Energy Systems
  - Techlam
  - Tenaris
  - V&M
- Regulators
  - U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration (PHMSA)
  - U.S. Department of the Interior, Minerals Management Service (MMS)

## 1.3 SCOPE

The original JIP scope consisted of several subtasks:

- Develop a systematic, risk-based approach to the integrity management of SCR field systems;
- Provide a framework for structured record-keeping to allow periodic demonstration of fitness for purpose and/or to justify extension of service life;
- Survey of SCR and component potential failure modes;
- Identify current best technology, emerging technologies, and technology gaps relating to for SCR inspection and monitoring;
- Develop worked examples of methodology;
- Provide a forum among JIP participants for informally sharing experiences in SCR integrity and design technology;
- Develop industry guidelines on SCR integrity management.

Due to the inclusion of more JIP participants, the IM methodology developed by the JIP was extended to both hybrid riser and top-tension riser (TTR) systems. For both of these riser systems, industry guidelines were developed. These guidelines include for each riser system:

- Application of integrity management methodology;
- Failure modes detailing the most likely mechanisms culminating in a structural inability of the riser system to produce fluid;
- Example integrity management measures for each failure mode

This document provides a summary of the inspection and monitoring measures and the general IM methodology that was developed by the JIP.

## 1.4 ASSUMPTIONS

It is a fundamental assumption in this JIP that all riser systems have been designed in accordance with a recognized industry code of practice for riser design.

Failure modes considered by this approach are associated with structural failure of a riser system (e.g. rupture or leakage) rather than flow assurance failures (i.e. blockage). Additionally, any failure of a riser component (e.g. buoyancy module) was treated as an intermediary step leading to the structural failure of the system.

## 1.5 DELIVERABLES

To date, the following reports and guidelines documents have been issued:

- SCR Inspection and Monitoring Methods (Rev. 0)
- Guidelines for the Integrity Management of SCRs (Rev. 1)
  - Appendix A: SCR Pipe
  - Appendix B: Mechanical Connectors
  - Appendix C: Ancillary Equipment
- SCR Integrity Management Strategy: Worked Example (Rev. 0)
- Guidelines for the Integrity Management of Hybrid Risers (Rev. 0)
  - Appendix A: Components
  - Appendix B: System Failure Modes
- Guidelines for the Integrity Management of Top-Tension Risers (Rev. 0)
  - Appendix A: Fluid Conduit System
  - Appendix B: Support Structure

Document management software was also developed over the course of the JIP and has been made available to participants.

All deliverables have been made available to participants via the SCRIM JIP website. The appendices for the guidelines documents detail riser system failure modes with example integrity management measures in a manageable manner.

# 2 INSPECTION AND MONITORING MEASURES

## 2.1 INTRODUCTION

Several monitoring and inspection technologies are available to operators to provide the information necessary to measure riser performance as part of an integrated IM program.

Information gained from the early monitoring systems has allowed operators to quantify structural response of risers and reduce some important design uncertainties. These initial monitoring systems also provided several 'lessons-learned' which have contributed useful input to the development of the next generation of monitoring capabilities.

## 2.2 INSPECTION & MONITORING TECHNOLOGY SURVEY

As part of the scope of the SCRIM JIP, an extensive list of vendors/manufacturers was identified who between them offered a variety of monitoring and inspection technologies.

The survey was based on information received from these vendors in the form of one or all of the following formats:

- Technical information and/or brochures
- Direct face-to-face meetings
- Completed (standard form) technical questionnaires
- Answer to detailed technical questions

A total of approximately forty companies were surveyed in all, representing a combination of both mature and emerging technologies.

A detailed examination of each technology was undertaken with the objective of providing the operators with information on each of the fundamental inspection and monitoring technologies offered by vendors, together with the deployment experience of specific technologies, the experience of individual companies and some desensitized project lessons learned.

## 2.3 MONITORING METHODS

A high-level overview of some of the key parameters that may be monitored as part of an IM program is presented in Figure 2-1. Such parameters are typically some of the key inputs into the riser design process, and therefore can provide a useful design validation or integrity check when monitored during service. A periodic analysis of riser integrity which had access to such monitored information might allow designers to calibrate models and validate design assumptions, thereby allowing an integrity check during riser operation.

Taking from Figure 2-1 the example of stress/strain monitoring, a more detailed breakdown of some of the fundamental technologies is presented in Figure 2-2 to illustrate the typical process by which the surveyed vendor information has been compiled and presented. An example is provided of the systems available for monitoring stress. The various technologies available are detailed (strain gauges, fibre optics, LVDTs). Also presented are details of the various sensors for each technology (e.g. metallic and silicone strain gauges) and the various transmission methods currently available to transmit the data to a central storage unit (copper conductors, fibre optics, acoustic modems).

A secondary goal of the industry survey was to survey emerging technologies for future possible SCR integrity application (e.g. fibre optics, direct fatigue measurement methods etc.). Some of these technologies are relatively mature and their implementation to SCRs may be what is relatively new. Furthermore, some of the technologies had yet to be implemented while some had recently been qualified or deployed.

In keeping with the monitoring goals of the SCRIM methodology, understanding the limitations and advantages of the various available monitoring and inspection methods has made it possible to group these techniques into the Strategic Inspection Levels (predictive, detective, basic) required to mitigate a given level of risk.

## 2.4 CURRENT TECHNOLOGY

Current sensor technology is capable of measuring and monitoring riser response precisely and accurately, using a variety of different sensors and methods. However the application of this technology to the offshore environment, where access is limited, installation is difficult and environmental conditions such as pressure and temperature may be onerous, can present challenges to the qualification, long-term durability, or other limits of such systems. Therefore, technology gaps have been detailed in terms of:

- Qualification or ability to deploy emerging technologies;
- Remaining uncertainties in design inputs and riser response.

## 2.5 REAL-TIME VERSUS POST-PROCESSED DATA

In certain situations real time data is necessary and useful to an operator. Examples of this may be vessel position and offset, operating temperature and pressure. In other situations the availability of real time data may be expensive to acquire or not of immediate use to an operator. An example of this might be vortex induced vibration (VIV) measurements, unless coupled to real-time fatigue software. Such data, if not practical to acquire and post-process on-line, may be later post-processed to determine accumulated fatigue damage and associated remaining fatigue life.

The requirement for real time data will typically have a consequential influence other factors in the design of a monitoring system, by determining the requirements for data transmission and analysis. Such a decision may be a cost issue for several of the monitoring technologies and whether to have an on-line vs. an off-line system is typically a strong driver in the design, specifications and ultimately the cost of any monitoring system.

## 2.6 SUMMARY OF INSPECTION AND MONITORING METHODS

A single inspection method is typically not capable of providing all of the information required from a riser monitoring program. A combination of complimentary inspection methods with analytical, metallurgical, operational history and process knowledge is necessary to provide a more complete picture of riser response. An integrated set of measures typically provides the most effective basis for the management of a riser. In order to achieve this goal a clear understanding of the limitations and advantages of each technique is necessary.

A single project may need to consider the monitoring of one or a small number of representative risers. Response may be inferred for other risers based on useful data from a single monitored riser combined with calibrated analytical models of others. Short term monitoring and inspection of a riser and environmental variables also has the potential to enable the operator to better understand the structural response of a riser, offering the potential to eliminate key uncertainties which increased perceived risk at the design stage.

**Figure 2-1 Breakdown of Monitoring Methods**

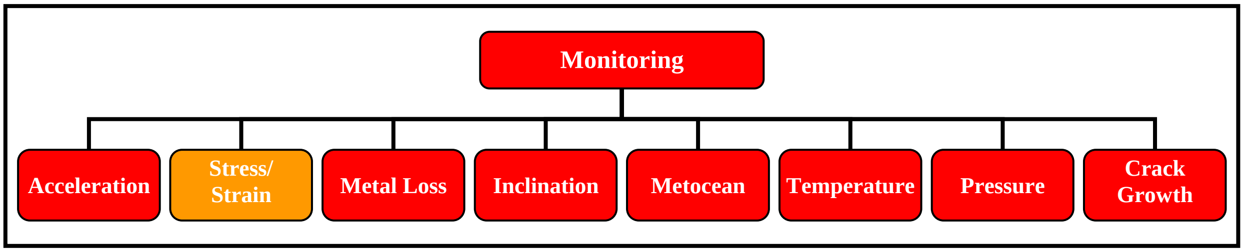
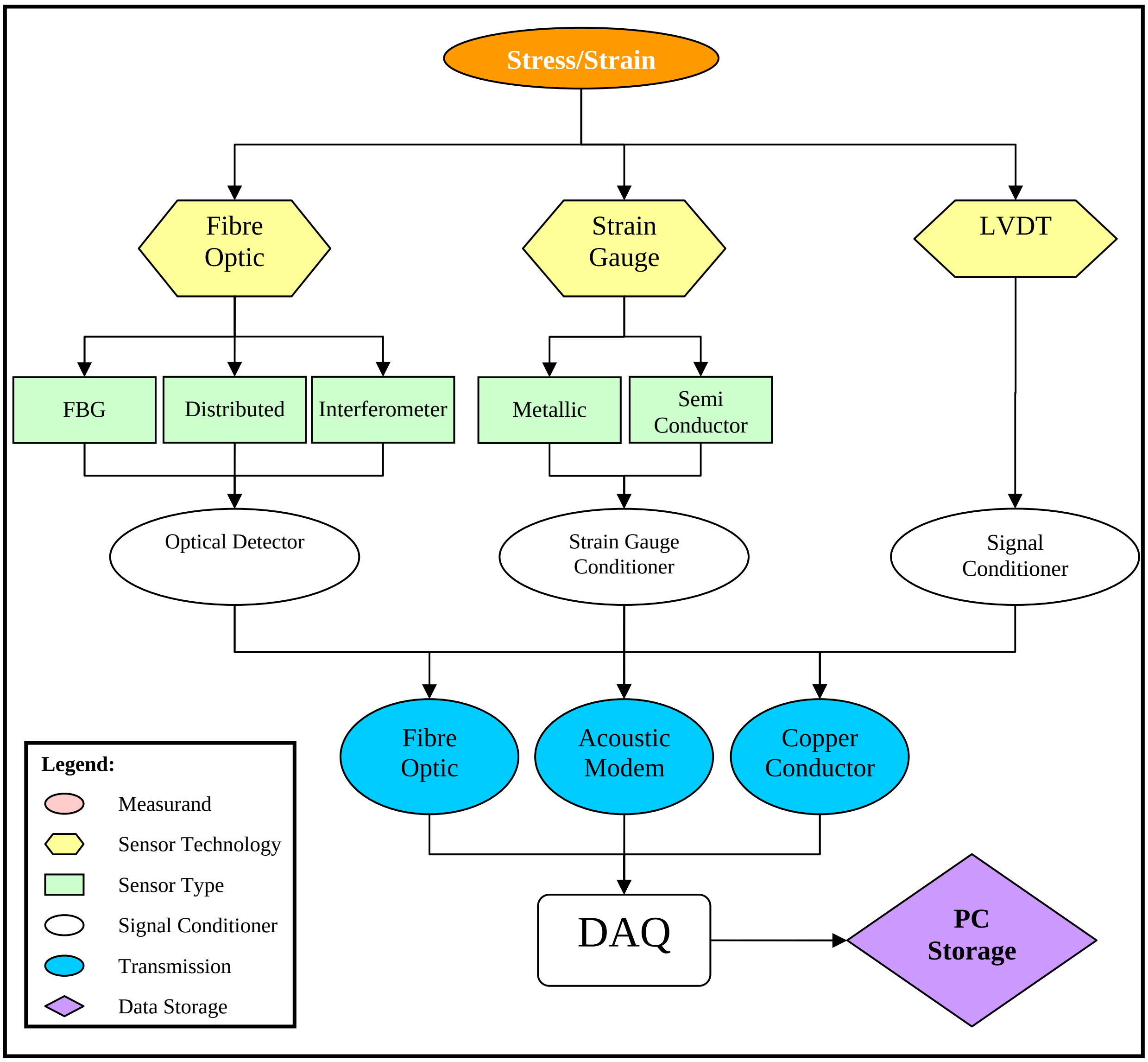



**Figure 2-2 Breakdown of Stress/Strain Monitoring Systems**



# 3 JIP IM METHODOLOGY

## 3.1 OVERVIEW

An overview of the approach proposed by JIP for the development and implementation of an Integrity Management Program for riser systems is presented in Figure 3-1. The methodology can be summarized as follows:

1. Subdivide the system into integrity groups based on similarity of service and risks to which groups of risers are exposed.
2. For each group, define the *Failure Modes* to which the integrity groups are exposed. Typically, the most onerous condition of the grouped items is considered when assessing *Failure Modes*.
3. Calculate an *Integrity Management Index* as the product of the *Probability* and *Consequence Indices* for each relevant *Failure Mode*. The *Probability Index* is a function of proximity to design limit and associated uncertainties; the *Consequence Index* quantifies the safety, environmental, and economical cost of a failure.
4. Assess whether any prevention or mitigation measures are available for the risk. In certain cases, prevention or mitigation measures may be more cost-efficient to implement than the in-service integrity management measures required to address a higher risk.
5. Develop *Integrity Management (IM) Strategy* consistent with the risks associated with relevant *Failure Modes*. An *IM Strategy* consists of a combination of the following available measures:
   - Monitoring Measures
   - Inspection Measures
   - Analysis and Testing
   - Operational Procedures
   - Preventative Maintenance Measures
   - Remedial Maintenance Measures

   Anomaly limits and implementation frequency for all measures are crucial components of any IM strategy.
6. Determine key issues and schedule for *Integrity Reviews*. The results of the SCR integrity management program are periodically reviewed relative to the anomaly limits, and summarized in a *Fitness Statement*. The *Fitness Statement* reports any deviations that need immediate and/or long term action and any updates to the IM Measures for the future.

The deliverables of the overall IM process are:

- *Integrity Management Plan*, which describes each of the IM Measures applied as part of the overall IM program together with their frequency of application. This document is updated and maintained throughout field life.
- *Periodic Fitness Statements*, which are the outputs of periodic reviews of system integrity. These represent a statement of continued fitness for purpose based on information gathered from the IM Plan.

## 3.2 SYSTEM SUBDIVISION

Where the system is composed of several different service functions or different designs, then the user should subdivide the system into component groups that share characteristics. Shared characteristics reflect similar applications, and may include:

1. Service function (e.g. production risers, water injection.);
2. Global configuration (e.g. all SCR through J-tubes);
3. Riser internal diameter;
4. Design conditions (e.g. pressure, temperature).

Where system components of similar characteristics are considered together, the most onerous condition of the group should be considered when assessing risk and developing integrity monitoring strategy. By grouping systems in this way, only one risk assessment from each application need then be considered.

## 3.3 FAILURE MODES

Fundamental to the approach developed by the SCRIM JIP was the need for a comprehensive list of *Failure Modes* for riser systems and their components. The SCRIM JIP put much effort into developing long-lists of failure modes for SCR, hybrid riser, and TTR systems through a combination of design and construction experience combined with consultation with component vendors and operators. Well over 200 failure modes were identified for each type of system, detailing the most likely mechanisms culminating in a structural inability of the riser system to produce fluid.

To facilitate risk assessment and the identification of mitigation and integrity management measures, *Failure Modes* were defined as the combination of each the following elements:

- ***Failure Initiator***, the event or process that initiates a failure mode;
- ***Failure Mechanism***, the sequence of stages after initiation which lead to ultimate structural failure (i.e. either rupture or leakage);
- ***Potential Mitigation Measures***, typical options available to the operator to mitigate and reduce high risk;
- ***Potential Design Uncertainties***, key 'unknowns' or uncertainties involved in the design of the riser and/or its components that may impact this failure mode.

An example of this format is presented in Table 3-1. A unique identification, or *Failure ID*, was assigned to each *Failure Mode* for easy reference.

Potential *Failure Modes* were presented in the appendices of each guidelines document by *Failure Driver*. *Failure Drivers* represent the generalized source of failure (such as fatigue or accidental damage) and allow for manageable assessment of relevant *Failure Modes*. For a particular integrity group, the list of *Failure Modes* can be reduced to exclude *Failure Modes* to which the integrity group is not likely exposed to during the design life.

The *Failure Modes* lists, though not exhaustive, were intended to include the most likely sources for riser system failure. A systematic hazard-identification (HAZID) process may be necessary to identify any additional *Failure Modes* to which the riser system may be exposed for a specific intended application.

## 3.4 RISK ASSESSMENT

A series of quantitative risk assessments of all relevant *Failure Modes* should be performed. The initial risk assessment is based on information available from the design basis. This assessment should later be updated to consider any anomalies or refinement of design knowledge.

The SCRIM JIP developed a modified indexing analysis, applicable to a variety of risk assessment philosophies and system types. The same method can be extended to include other subsea systems.

For an indexing analysis, risk is defined as the product of one score representing the probability of failure (*Probability Index*) and another representing the consequence of failure (*Consequence Index*). This relative risk is referred to as an *Integrity Management Index* (IMI). The IMI is used to guide the user towards recommending available IM strategies.

A high *Integrity Management Index* indicates that integrity management measures are required, and does not necessarily imply high risk of failure. It is always assumed that any system with a high risk of failure is not allowed to continue in service.

For the recommended method, the *Probability Index* was defined to allow a transparent, systematic assessment of risk, while being flexible to operator experience. Methods for mitigating risk typically modify the *Probability Index*, instead of the *Consequence Index* or directly modifying the IMI.

The *Integrity Management Index* approach was developed in order to:

- Avoid emotive terms in the classification of integrity management needs;
- Allow easy adaptation between various operators, where risk may be defined differently;
- Avoid possible misinterpretation of high index as high probability of failure;
- Provide clear, easily applied assessment rules;
- Ensure methodology gives the "right" answer in terms of IM needs for some key Failure Modes;
- Provide guidance in selecting integrity strategies.

### *3.4.1 PROBABILITY INDEX (P)*

The *Probability Index*, P, was defined so that risks associated with how the system is designed are separated from risks inherent to uncertainties in design theory or application.

It is assumed that any system in service is designed according to code. For example, a riser whose design pressure is greater than its burst pressure would not knowingly be put into service. *Failure Modes* where the system is designed well within the relevant code allowable are typically eliminated, save where significant uncertainties exist.

The inherent uncertainties in the design methodology were classified in terms of:

- Technology Step-Out (TSO)
- Design Uncertainties (DU)
- Anomalies (A)

*Technology Step-Outs* account for the uncertainty associated with new applications or technology step-outs from existing applications. For example, the use of mechanical connections between SCR joints is currently a technology step-out.

*Design Uncertainties* reflect uncertainties concerning design basis input and/or analytical technique. Some typical design basis concerns include:

- Metocean criteria
- Well fluid characteristics
- Soil stiffness
- Operational temperature / pressure

Analytical uncertainties portray the limits of applicable theories or modeling techniques. One of the most prominent examples is vortex-induced vibration response. Other examples include flexible joint elastomer degradation and SCR touchdown point response modeling. Many common design uncertainties are listed with associated *Failure Modes*.

*Anomalies* reflect uncertainty concerning predicted behavior due to some significant level of defect. Anomalies can occur at any stage of the system life. In general, anomaly significance is determined by:

1. Size of anomaly;
2. Effect on code compliance.

Anomalies always require an *Ad Hoc Engineering Assessment* to determine their significance. Examples of anomalies include:

- Larger than anticipated wall thicknesses that were approved by the operator;
- Greater than anticipated fatigue damage accumulation due to hanging on tensioners during weather down time;
- Occurrence of extreme metocean conditions.

Anomaly limits (Section 3.5.3) define when an anomaly has occurred.

The JIP methodology allows user expertise to quantify the uncertainty in design input or prediction of response. However, the effectiveness of the method relies on the knowledge possessed by the developer of *IM Strategy*.

Thorough and well chosen *Input Sensitivity Studies* can provide useful assistance in understanding the effect of a critical design input's variability on response (e.g. wall thickness tolerances' effect on stress or fatigue life). For this reason, strong benefit was attributed to carefully choosing the *Design Input Sensitivity Studies* which should be performed during the design process.

### *3.4.2 CONSEQUENCE INDEX (C)*

The *Consequence Index*, C, was defined by a scale of increasing severity, which accounts for all safety, environmental and operational consequences of failure. Failure is always defined as the termination of the integrity group's ability to perform its required function.

*Safety consequences* consider potential impact on any population near the integrity group, typically in terms of injury and death. For subsea *Failure Modes*, these consequences may be broadly defined by proximity to a population. If a riser leaks in the touchdown zone, it will not likely cause a direct threat of injury or death to the personnel topside.

*Environmental consequences* only consider damage to the environment. These consequences refer to the ecological concerns, such as the possible impacts of failure on marine mammals, birds, fish and shellfish, and the natural habitats that support these resources. An Environmental Impact Assessment is a good resource for determining the environmental consequence.

*Operational consequences* consider the significant monetary costs associated with failure, specifically loss of operating capability. Typically, these are assessed in terms of shutdown time or reduction in overall productivity.

A simple example scale is provided in Table 3-2. This index was primarily driven by operational and environmental concerns. Safety consequences were only broadly defined on the overall consequence. As such, the *Consequence Index* assigned to a specific *Failure Mode* only varies over the life of the integrity management cycle if there is some significant change to the integrity group.

The proposed integrity management approach is robust enough to allow the consequence index used for a given application to be adjusted to align with the consequence categories used by an individual operator for other safety critical systems.

### 3.4.3 INTEGRITY MANAGEMENT INDEX (IMI)

The integrity management index was defined as:

IMI = P x C

Where

P = Probability index

C = Consequence index

This allowed implementation across the industry and flexibility for different operators with different risk assessment approaches.

The value obtained from this calculation is used to choose from a variety of integrity techniques to ensure the continued and safe operation of the system.

### 3.4.4 MITIGATION MEASURES

*Mitigation Measures* are any action that will reduce risk, and help form the preliminary basis for any IM strategy. Mitigations always reduce the IMI, typically by modifying the *Probability Index*. These measures have been classified as either fabrication or strategical measures.

*Fabrication measures* require some sort of fabrication to implement, such as applying strakes to an SCR to mitigate VIV. While some of these measures can be implemented retroactively, most must be added during the design phase. These typically modify the *Basic Probability Index*, $P_o$.

*Strategical measures* emphasize IM measures that must be included in the IM strategy, such as requiring the use of fresh water during a hydrotest. Some of these broad measures might mitigate the *Consequence Index*. Most of these measures modify the *Uncertainty Index*, U.

*Failure Modes* which carry an unacceptable risk should be addressed by applying mitigation measures. The *Failure Modes* with high IMIs after mitigation should be specifically addressed as part of the detailed integrity management strategy.

## 3.5 IM PLAN DEVELOPMENT

Following a risk assessment, each failure mode is assessed to determine the required level of integrity management. Four *Strategic Inspection Levels* (SILs) were identified to denote these integrity management levels. Combinations of *IM Measures* are selected according to SIL. An *IM Strategy* details how these measures are implemented for each failure mode, and form the basis of the *IM Plan*.

### 3.5.1 STRATEGIC INSPECTION LEVELS

Four *Strategic Inspection Levels* were used to relate the degree of required integrity management to the degree of risk identified for a particular failure mode. These levels, which are related graphically to the risk matrix in Figure 3-3, were generically defined as:

5. *None*: Integrity management is not required;
6. *Basic*: Basic integrity management is required, typically based in part on regulatory requirements;
7. *Detective*: Detection of failure initiation or a critical stage in the failure mechanism is required;
8. *Predictive*: Integrity management measure must be capable of predicting the remaining life.

Predictive IM measures require either the direct monitoring of the progress towards failure or the assignment of a degradation model to failure. A failure degradation model analytically calculates the progress and the associated remaining time to failure, based on the input of measured data.

Realistically, all systems require some IM strategy. Each failure mode of an integrity group will have an individual SIL. As such, no system will have a SIL of *None* for all *Failure Modes*. It is also unlikely that a system will not require at least a SIL of *Basic* for all *Failure Drivers*.

The typical *IM Measures* presented in the appendices of the guideline documents included each method's applicability to the different SILs. However, it is up to the judgment of the user to:

1. Define the IMIs associated with each SIL;
2. Categorize the SILs available for each procurable measure;
3. Assess where, when and how to implement the measures.

### *3.5.2 INTEGRTIY MANAGEMENT MEASURES*

Several measures are available to maintain the integrity of a field system. Based on the required *Strategic Inspection Level* for the IMI, an integrity management strategy is selected from any combination of measures. For simplicity, these measures were identified under the following categories:

- Inspection Measures
- Monitoring Measures
- Analysis & Testing
- Operational Procedures
- Preventative Maintenance Measures
- Remedial Maintenance Measures

Broadly, *inspection* and *monitoring measures* refer to obtaining information about the system. *Analysis & testing measures* refer to how the information is assessed. *Operational procedures*, *preventative maintenance measures* and *remedial maintenance measures* refer to actions designed to prevent failure.

*Inspection Measures* serve as periodic critical appraisals. Increasing frequency usually denotes increased IMI levels. For subsea systems, inspection options may require innovation. In particular, SCRs subsea inspections are currently restricted to visual ROV / AUV limits.

*Monitoring Measures* provide approximately continuous measurements of either environmental or structural conditions. Current sensor technology is capable of measuring and monitoring response extremely precisely and accurately, using a variety of different sensors and methods.

*Analysis & Testing Measures* are designed to verify design assumptions and assess the impact of any variations. These measures include evaluation of monitoring and inspection equipment. Reanalysis of fatigue under monitored metocean conditions to determine the actual remaining life is a typical *A&T Measure*.

*Operational Procedures* establish specific guidelines to avoid the most common risk-critical situations during any planned operation. Some examples include abandonment & recovery procedures, lifting & handling procedures, and vessel exclusion zones. Common ad-hoc events are also addressed in these procedures, such as dropped object protocols.

*Preventative Maintenance Measures* are modifications to system components prior to an expected failure initiation or critical stage of failure mechanism. They are scheduled to prevent premature failure by servicing or replacing equipment to reduce wear and maintain optimal performance. Scouring marine growth, replacement of anodes, and recalibration of instrumentation are some examples. Manufacturer recommendations are a primary source for these measures.

*Remedial Maintenance Measures* are modifications to system components to address an unlikely failure initiation or critical stage of failure mechanism. For example, flexjoint degradation due to anomalously high temperature may require the flexjoint to be replaced. These measures are always initiated by an *Ad-Hoc Engineering Assessment* after some *Anomaly Limit* has been exceeded.

The *IM Measures* feed into each other. Dropped object protocols should be included in *Operational Procedures*. Following implementation of this procedure, additional *monitoring* or *remedial maintenance measures* may be required.

Table 3-3 provides further examples of available integrity management options.

### *3.5.3 ANOMALY LIMITS*

The bounds of acceptable behavior, or *anomaly limits*, for a system must be defined for each non-maintenance *IM Measure* implemented. *Anomaly limits* are set within the most rigorous design, operating, and qualification limits of the integrity group. These anomaly limits establish when, prior to design exceedance, further action is required.

Where practical, quantitative anomaly limits should be defined. All subsequent IM actions are compared to the predefined anomaly limits.

Some typical anomaly limits may include:

- Acceptable $H_2S$ percent content in production fluid;
- Minimum detection limits for crack width, length, and depth.

Anomaly limits are not necessarily the same as design limits. They are used to determine whether an observed variation qualifies as an anomaly. Anomalies can occur at any point during the service life, such as:

- Manufacture
- Installation
- Operation

All anomalies require an *Ad-Hoc Engineering Assessment* to examine the significance of the anomaly. Significance is judged at the very least on:

- How badly the anomaly limit is exceeded;
- If the anomaly affects code compliance.

Any significant anomalies require an updated risk assessment, and the *Ad-Hoc Engineering Assessment* should include any updates to the IM plan.

These assessments are discussed in Section 3.6.3.

### *3.5.4 IM PLAN*

An *IM Plan* is developed from the *IM Strategies*, expressly detailing all *IM Measures* with frequency of implementation and anomaly limits. A detailed description and schedule for at least one future integrity review should be included, although a schedule for several such reviews is not precluded. Common *IM Plan* components include:

- Identification of critical failure modes;
- All Anomaly Limits;
- Provisions for remediation of common conditions found during integrity assessments, listed by specific problem;
- Recordkeeping provisions;
- Detailed inspection checklists;
- Personnel requirements to implement *IM Plan*;
- Procedures for satisfying any regulatory requirements regarding integrity management programs;
- Schedule and guidelines for *Integrity Reviews*, which provide for continual evaluation and assessment of the system.

A first-pass *IM Plan* typically is developed during the design phase of a project, so that any *IM Measures* requiring hardware can be incorporated into the design. Any significant alteration to the system or its' operational conditions may require a reassessment of the risk assessment and *IM Plan*. Additionally, periodic reviews are required to:

- Determine if the system behavior has been adequately assessed;
- Validate any uncertainties associated with high risk failures;
- Verify the *IM Plan* is implemented as specified;
- Evaluate the effectiveness of the *IM Plan*.

A preliminary schedule and detailed procedure for at least the first *Integrity Review* are critical components of the *IM Plan*.

## 3.6 INTEGRITY REVIEWS

*Integrity Reviews* evaluate the performance, service conditions, and *IM Measures* of the system and determine if any modifications are required. Several types of reviews are necessary over the life of the system:

1. Commissioning Assessment
2. Periodic Integrity Review
3. Ad Hoc Engineering Assessment
4. Life Extension Assessments

A *Commissioning Assessment* is conducted to determine if the *IM Plan* should be updated due to any anomalies or non-conformances during fabrication and installation. *Periodic Integrity Reviews* assess the system's in-service condition over prescribed intervals, while *Ad Hoc Engineering Assessments* evaluate the significance of any anomalies. *Life Extension Assessments* are conducted towards the end of expected service life, to determine if any extension is allowable.

After an *Integrity Review*, a *Fitness Statement* is issued. Details for the next *Integrity Review* and any changes to the *IM Plan* are specified in a *Forward Action Plan*. The next *Integrity Review* will use the *Fitness Statement* as a basis for comparison.

### *3.6.1 COMISSIONING ASSESSMENT*

A *Commissioning Assessment* is conducted to assess the accumulated effect any modifications during fabrication and installation may have on the system performance. Any anomalies should be identified in manufacturing *Non-Conformance Reports* (NCRs) and installation record books. These anomalies may contribute additional *Failure Modes* which require an update of the risk assessment and *IM Plan*, as described by the process flow chart of Figure 3-1.

### 3.6.2 PERIODIC INTEGRITY REVIEW

A *Periodic Integrity Review* assesses the in-service performance, service condition, and *IM Measures* of the system. Numerous reviews are completed during the life of the system, based on the *Strategic Inspection Level* and the intent of the review. *Periodic Integrity Reviews* were classified as:

1. System Performance Assessments
2. Design Basis Validations
3. Plan Implementation Assessments
4. Plan Effectiveness Assessments

***System Performance Assessments*** determine if the system's behavior has been consistently within the prescribed *Anomaly Limits* since the previous *Integrity Review*. The results of all *IM Measures* and *Ad Hoc Engineering Assessments* from this cycle are reviewed, comparing performance measures to pre-defined *Anomaly Limits*. The frequency for these assessments is determined by the implementation frequency associated with the relevant *IM Strategies*.

A *System Performance Assessment* serves two distinct purposes. It ensures that anomalies are not overlooked, and provides a convenient benchmark of the system performance. All inspection data, monitoring data, analysis & testing results, and maintenance records should be reviewed, and any non-working equipment identified.

A ***Design Basis Validation*** examines key design inputs and any inherent uncertainties in the design methodology. As part of this process, the appropriateness of the original *Design Basis* should be checked against actual operating conditions and up to date design practices.

The frequency of review is typically driven by the most critical failure modes for an *Integrity Group*, and emphasis is placed on the design uncertainties associated with these failure modes. A *Design Basis Validation* might typically occur once every 5 years.

A ***Plan Implementation Assessment*** reviews all *IM Measures* to ensure that they have been enacted as specified in the *IM Plan*. Some items verified are:

- *IM Plan* measures are all in place;
- Monitoring devices have been calibrated properly;
- Analyses comply with approved methods;
- Dropped Object Protocols have been followed for any incidents;
- Preventative maintenance schedule has been observed.

A *Plan Implementation Assessment* is typically justified after any change to the *IM Plan*. Additionally, this review might be conducted every 5 years to ensure validity of *IM Measure* results.

A ***Plan Effectiveness Assessment*** examines if the *IM Plan* has successfully maintained the integrity of the system. Regulatory and company requirements typically drive review frequency and define "successful." In general, the following items should be assessed:

- Does the *IM Plan* meet regulatory and company standards?
- Have any failures occurred or any *Failure Mechanisms* progressed past their critical stage unnoticed?
- Are more effective measures available?

Any deficiencies at minimum require a change in frequency of *IM Measures*. New *IM Strategies* may be selected for *Failure Modes* insufficiently managed. New, more effective *IM Measures* are implemented if they are significant benefit to the *IM Plan*.

### 3.6.3 AD HOC ENGINEERING ASSESSMENT

Whenever an anomaly occurs, an *Ad Hoc Engineering Assessment* is required to examine the significance of the anomaly. This assessment should be carried out as soon as possible after an anomaly has been detected, and should not wait for the next periodic review. Significance is judged at the very least on:

- The extent by which the anomaly limit is exceeded;
- If the anomaly affects code compliance or safety.

Any significant anomalies require an updated risk assessment and *IM Plan*. Some typical anomalies include:

- Metocean conditions beyond anomaly limits (i.e. post-extreme event)
- Occurrence of defects or cracks;
- Re-qualification after occurrence of accidental loads;
- Altered service conditions.

All *Ad Hoc Engineering Assessments* must include an anomaly specific investigation and an assessment of anomaly's impact on the system. If possible, factors that affect the anomaly's significance are identified. If the anomaly is assessed to be significant, some further action is required. This may include:

- Validation of uncertainties or design inputs;
- Reassessment of *Anomaly Limits*;
- Preventative maintenance;
- Additional *IM Measures*;
- Increased frequency of existing *IM Measures*.

Actions should be implemented based on a revised risk assessment for the riser, with an increased *Anomaly* rating for the *Uncertainty Index*.

Typical additional *IM Measures* include:

- Retrofit temporary or permanent monitoring equipment;
- Removal of component for testing or repair;
- Reduced service life;
- Replacement schedule for component.

*Remedial Maintenance Measures* are always initiated by a failure or an *Ad Hoc Engineering Assessment* after some *Anomaly Limit* has been exceeded.

### 3.6.4 LIFE EXTENSION ASSESSMENT

The service life of the system should be reevaluated if any of evaluations in the *Periodic Review* show that the service life does not meet the design requirements. An example of this may be that an anomaly occurs which reduces the remaining service life of the riser.

If an operator wishes to extend the life of an SCR past its original design, a reevaluation of the design life is required. This assessment should include a new Design Basis, based on any updated information. It should consider fatigue life, extreme response, and other factors which may affect the response or service life of the system.

### 3.6.5 DELIVERABLES

The deliverables of the *Integrity Review* process are typically a *Fitness Statement* and a *Forward Action Plan*.

#### 3.6.5.1 FITNESS STATEMENT

A *Fitness Statement* reports the current condition of the *Integrity Group* and highlights any critical issues pertaining to it from the *Integrity Review*. The function of a *Fitness Statement* is to report ongoing fitness for purpose to the operator.

The *Fitness Statement* must include:

- Scope of the fitness assessment;
- Details of monitoring or inspection results assessed as part of the review;
- Comparison with predefined anomaly criteria;
- Deviations that need immediate and long term corrective action or maintenance;
- Recommendations for when to conduct and what should be reviewed during the next evaluation;
- Exceptions that are not addressed within this fitness evaluation.

Guidelines for the *Fitness Statements* should be specified in the *IM Plan*. It was recommended that the *Fitness Statements* are structured to meet regulatory compliance reporting requirements.

#### 3.6.5.2 FORWARD ACTION PLAN

The *Forward Action Plan* specifies any necessary modifications to the *IM Plan*. Corrective action or maintenance is required only if anomalies come to light from the *Integrity Review*. Frequencies for *IM Measures* and *Integrity Reviews* may also be altered on the basis of *Integrity Review*, with possible revision as new techniques, methods or data become available. The *Forward Action Plan* should address all actions for at minimum the next *Integrity Review* cycle.

The *Forward Action Plan* must include:

- Forward plan for *IM Strategies*;
- Information gained through preceding reviews;
- New knowledge regarding the application of *IM Measures*;
- Updated system uncertainties;
- New analysis techniques and methods.

**Figure 3-1 Flowchart of Riser Integrity Management Process**

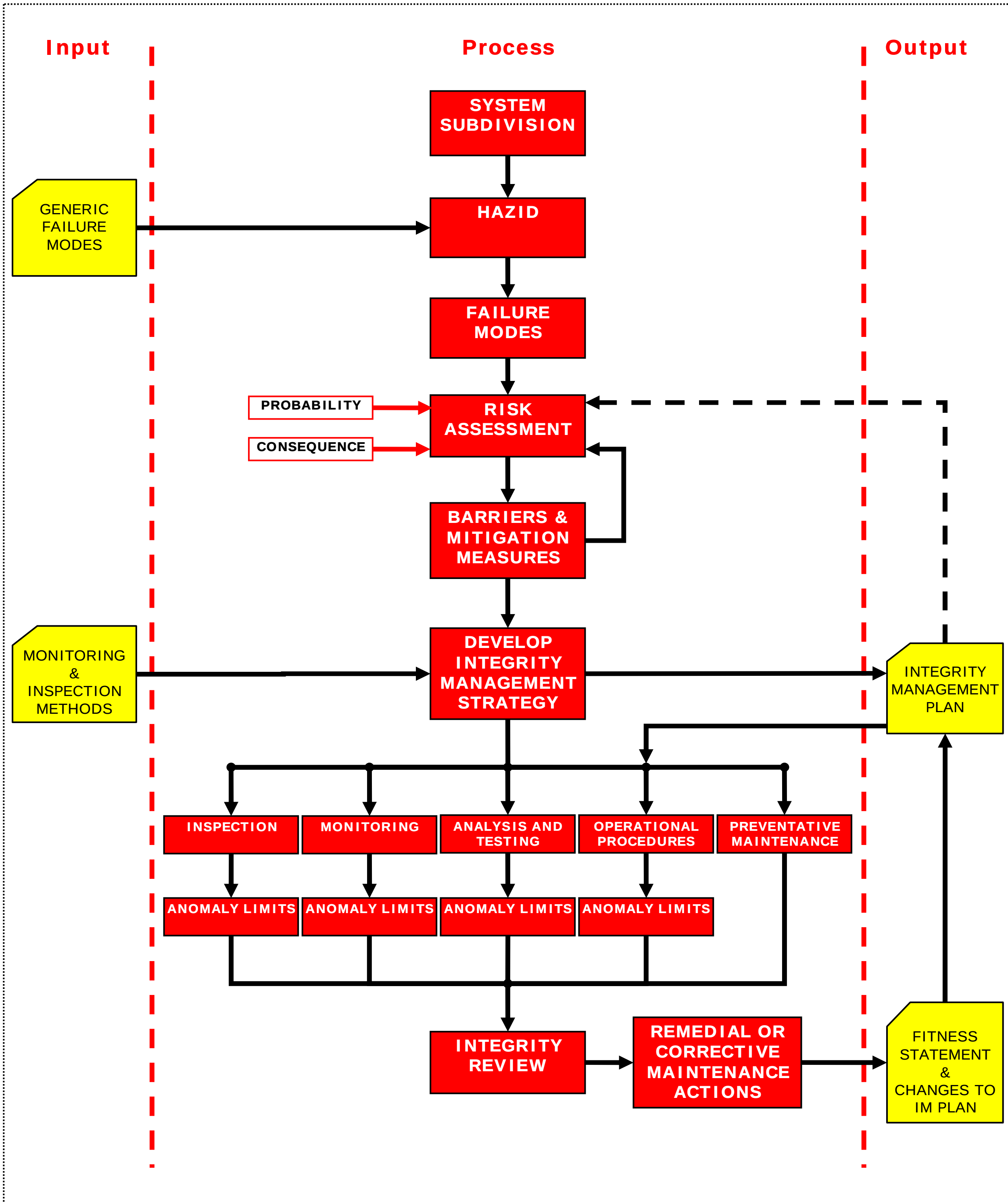


**Table 3-1 Example Failure Modes**

| Failure Mode | | | | Potential Uncertainties | Potential Mitigation Measures |
|---|---|---|---|---|---|
| **ID** | **Mode** | **Initiator** | **Mechanism** | | |
| **SL1** | Pipe rupture due to excessive facility offset (Inadequate mooring) | Mooring line failure due to inadequate design, leading to excessive facility offset | 1. Mooring line failure and excessive excursions<br>2. Excessive wall tension<br>3. Rupture | • Vessel Motions<br>• Mooring line response<br>• Metocean conditions<br>• S/N data | • Increased mooring design conservatism<br>• Move vessel/ change out strategy<br>• Better specifications for metocean and motion inputs to riser design<br>• Riser design review when out of specification<br>• Two line failure survival mooring line design |
| **SL2** | Pipe rupture due to excessive facility motions (Facility VIM) | Excessive surface currents inducing facility VIM | 1. Vortex induced motions<br>2. Excessive stress cycling<br>3. Rupture | • Vessel Motions<br>• VIM modeling<br>• Mooring line response<br>• Metocean conditions<br>• S/N data | • Winch to increase mooring stiffness<br>• Move vessel<br>• Better specifications for metocean and motion inputs to riser design |

**Figure 3-2 Sample Risk Matrix**

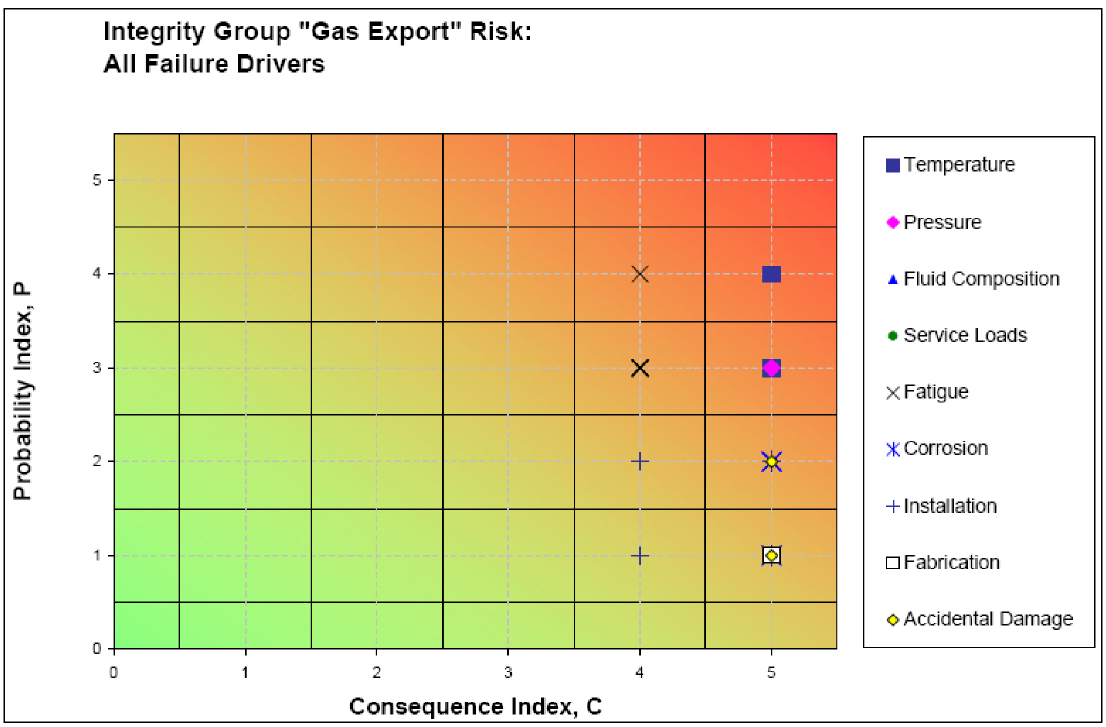


**Table 3-2 Example Consequence Index**

| Rating | Description |
|---|---|
| 1 | Non-hydrocarbon, low-pressure riser. |
| 2 | Non-hydrocarbon high pressure riser greater than 1000ft from a populated facility, whose failure has a low impact on total field productivity. |
| 3 | Non-hydrocarbon high pressure riser greater than 1000ft from a populated facility, whose failure has critical impact on total field productivity. |
| 4 | Hydrocarbon riser more than 1000ft from a populated facility **OR** non-hydrocarbon, high pressure riser within 1000ft of a populated facility. |
| 5 | Hydrocarbon riser any part of which is located within 1000ft of a populated facility. |

**Figure 3-3 Example Strategic Inspection Levels as a function of Probability and Consequence**

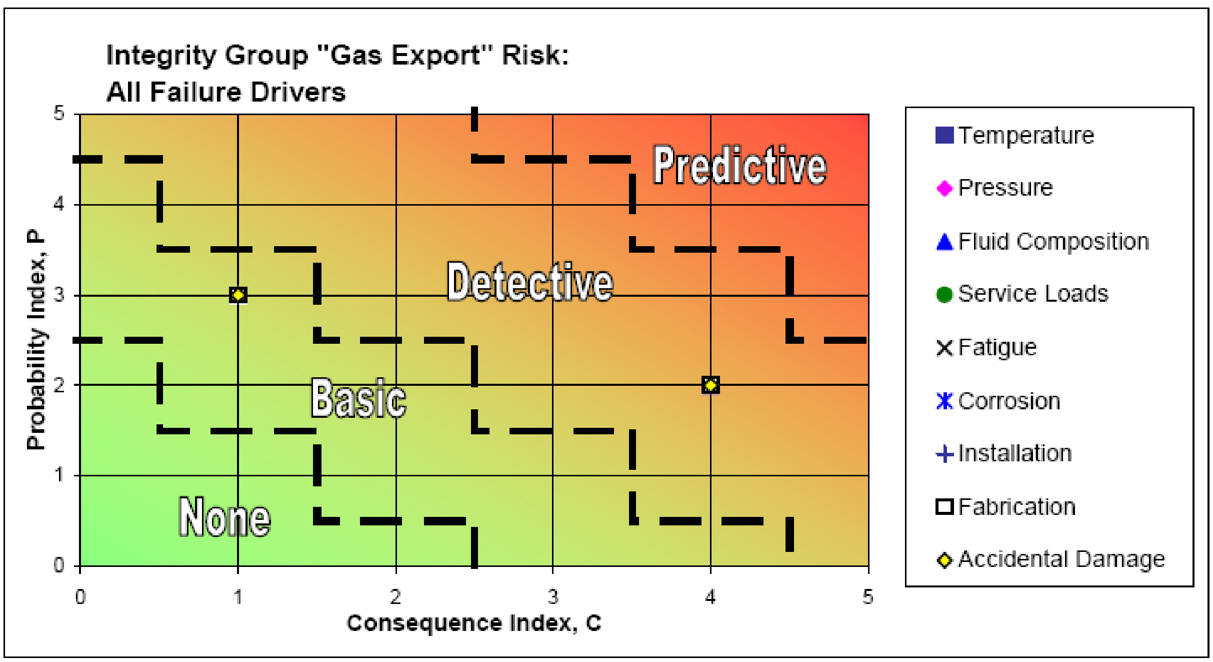


**Table 3-3 Example Integrity Management Measures**

| Failure Driver | IM Method | Typical Integrity Management Measure |
|---|---|---|
| Temperature | Inspection | • ROV visual inspection for evidence of temperature degradation of materials (e.g. flex-joint elastomer or steel riser coating) |
| | Monitoring | • Temperature at subsea tree, downhole, on flexible joints, production facility |
| | Analysis & Testing | • Reanalysis of pipe corrosion<br>• Flexible pipe polymer degradation under measured temperature conditions |
| | Operational Procedures | • Regulation of product temperature in export risers with process coolers |
| | Preventative Maintenance | • Review and adjustment of chemical dosage (e.g. chemical inhibitor) |
| | Remedial Maintenance | • Retrieval and repair of flexjoint |
| Pressure | Inspection | • ROV inspection |
| | Monitoring | • Pressure at subsea tree, downhole, and production facility |
| | Analysis & Testing | • Reanalysis of pipe corrosion, flexible pipe polymer degradation under measured pressure conditions |
| | Operational Procedures | • Controlled shut-down to prevent rapid decompression in pipe bore |
| | Preventative Maintenance | • Scheduled maintenance of valves and actuators |
| | Remedial Maintenance | • Retrieval and repair of flexjoint, due to pressure pulsation damage |
| Fluid Composition | Inspection | • Inspection of corrosion coupons |
| | Monitoring | • Corrosion probe monitoring produced fluid $H_2S$, $CO_2$ content |
| | Analysis & Testing | • Reanalysis of corrosion models<br>• Reanalysis of sour service fatigue<br>• Material testing |
| | Operational Procedures | • Fresh water required for hydrotest<br>• Fresh water / biocide in flooded SCR wet-parked |
| | Preventative Maintenance | • Chemical injection strategy |
| | Remedial Maintenance | • Wax remediation pigging<br>• Hot-oil flushing |

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