ANNEX III
Deepwater Research Projects

CONTENTS

III.1 SUMMARY OF PROJECTS

This section of the report provides a summary of some significant recent research initiatives and challenges particular to the deepwater oil and gas production:

- Subsea riser designs;
- Integrity management;
- Corrosion.

III.1.1 SUBSEA RISER DESIGN

Subsea risers provide the flow path for fluid from the seabed to the top processing facility. Steel Catenary Risers are relatively inexpensive solution to deepwater oil and gas production. Fatigue stresses associated with extreme storms, vessel motions, and Vortex Induced Vibrations (VIV) are critical to SCR performance. The deepwater project under riser design addressed topics related to subsea riser fatigue design and riser thermal insulation.

III.1.1.1 Project No. 622 – Impact of Marine Growth on Pipeline Risers for Floating Production Facilities

ROV inspections had shown in recent years that marine growth may extend much deeper in the water column than the first 150ft of the water column that is recommended by the current riser design standard (1998 API RP 2RD) for assessment. In response, MMS funded a study of the impact of marine growth (fouling) on the performance of deepwater pipeline risers for floating facilities, in terms of stress and fatigue. The results included research results and establish technologies available for marine growth inspection, removal and mitigation.

Although industry response was limited, it was confirmed that soft marine growth has been observed down to 2000 ft salt water. Hard marine growth has been observed on the floating facility hulls and support structures, also at depths greater than anticipated. The observed marine growth did not exceed the thickness limits set forth in API RP 2RD.

The additional marine fouling had limited impact on steel catenary risers (SCR) strength and wave-induced fatigue response, which is representative of the most typical deepwater riser pipeline systems. However, deeper marine growth profiles may have more significant impact on weight-sensitive systems (such as TTRs) or systems that are fatigue-critical in the hang-off region (flexible risers), which will become more prevalent amongst deepwater applications in future years.

Marine growth inspection and removal techniques are mature applications, with little change in the last 15 years. The primary focus in industry is the development of anti-fouling coatings without tributyl tin (TBT), such as self polishing copolymer (SPC) biocidal coatings.

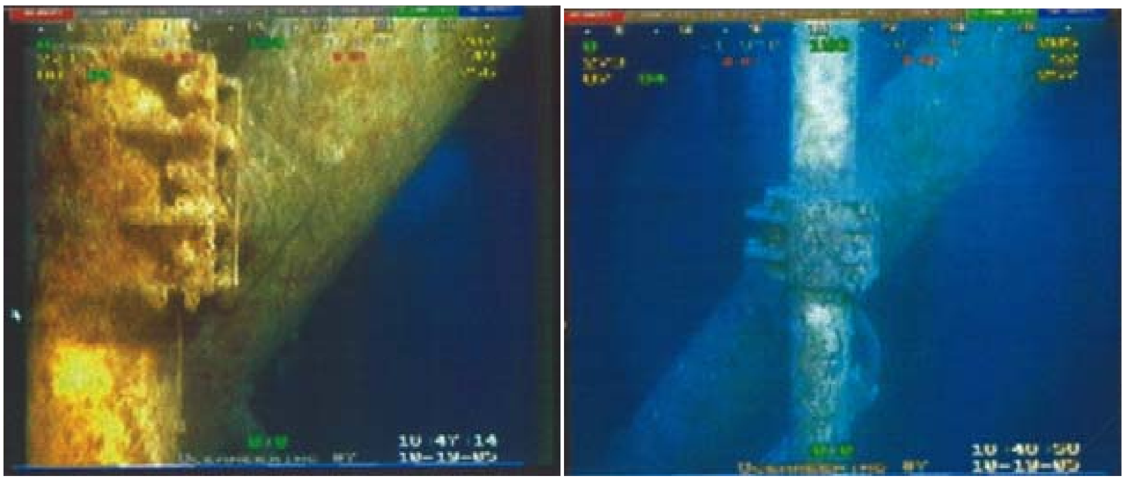


Figure III.1: Examples of marine growth

III.1.1.2 Project No. 572 – Deepwater Riser Design, Fatigue Life and Standard Study Report

Steel Catenary Risers (SCRs) and Flexible Catenary Risers (FCRs) are proven solutions for deepwater oil and gas production. The study was carried out to review the current industry practices for the analysis and design of pipeline risers on floating structures and reported failures. The recommendations and conclusions from this study will form a useful input for riser design, analysis, future studies and regulatory guidance.

III.1.1.3 Project No. 510 – Seafloor Interaction with Steel Catenary Risers

As oil and gas production continues to move from deepwater to ultra deep water, fatigue stresses associated with extreme storms, vessel motions and VIV are critical to SCR performance. The touchdown zone (TDZ) is where the riser contacts the seabed and often proves to be the point where bending stresses and fatigue damage are highest.

While linear elastic models have provided insights into the seafloor-riser interactions, full scale model tests have shown that riser seafloor interaction involves complex non-linear processes involving trench formation, non-linear soils stiffness, finite soil suction and breakaway of the riser from the seafloor. The study was carried out to assess soil-riser interaction based on a model comprising a linear-elastic pipe supported by non-linear springs representing the soil.

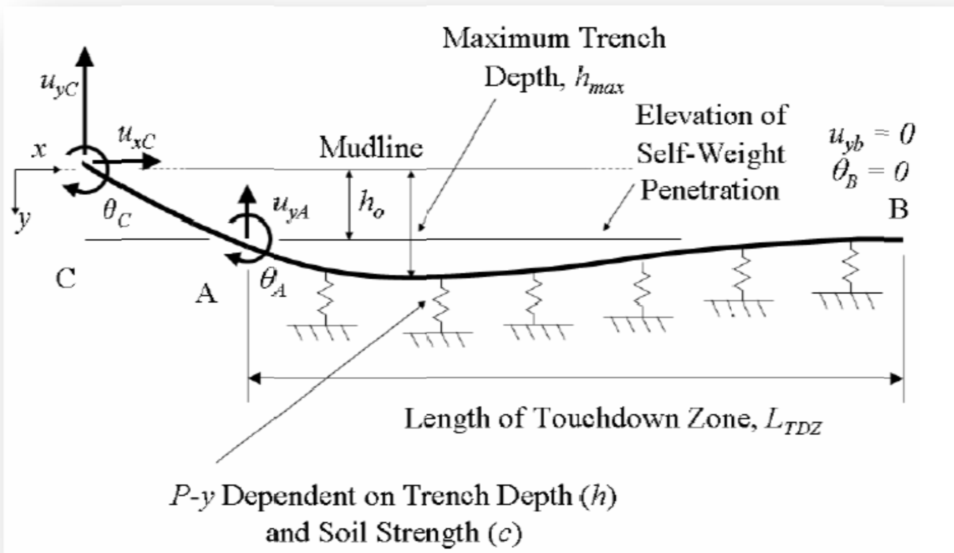


Figure III.2: Spring Pipe Model

III.1.1.4 Project No. 509 - Interstitially Insulated Pipe

Several insulation techniques have been developed to overcome the flow assurance issues associated with low production fluid temperature in the offshore energy industry. These techniques often have severe limitations such as damage to insulation due to large hydrostatic pressure differential and installation loads. For pipe in pipe offshore applications, coaxial pipe with a low conductivity screen mesh added between the inner and outer pipe has potentials to increase the insulation performance and be less susceptible to damage caused by installation and service loads.

This project investigated the benefits of coaxial pipe with a low conductivity screen mesh added between the inner and outer pipe for a pipe in pipe application. It was shown that this method of pipe insulation is feasible and could increase pipe's thermal efficiency.

With Thermocouples

With Insulation Applied

Figure III.3: Prototype Pipe

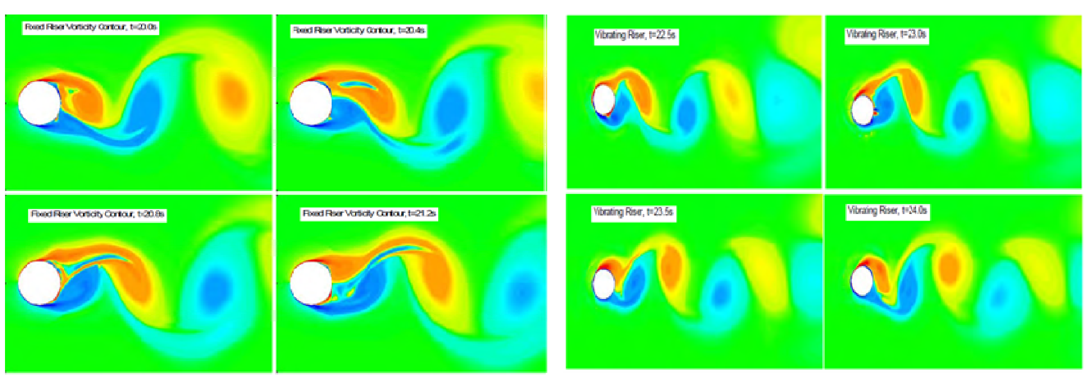
III.1.1.5 Project No. 494 – New Touch Down Zone (TDZ) Solutions for Steel Catenary Risers (SCRs) – Development and Qualification of Alternative Design Solutions

The use of SCRs in deepwater with floating units is challenged by high fatigue damage estimated in offshore and onshore welds at the SCR touchdown zone (TDZ). A Joint Industry Project (JIP) was carried from 2004-2007 to develop new design solutions and undertake qualification tasks for four (4) TDZ design alternatives with the aim of improving the fatigue life performance by a factor of 10 or more. As a result of significant qualification tasks undertaken in the JIP, progress was made to successfully bring the TDZ solutions to a technology ready level (TRL) for consideration at front end engineering design (FEED) stage.

Figure III.4: Fatigue Testing of Upset SCR welded Joints

III.1.1.6 Project No. 481 – CFD Simulation of a Riser VIV

Vortex Induced Vibration is an important fatigue issue in the design of deepwater riser system. Many of the available software tools that have been developed for riser VIV are based on empirical formulas that rely heavily on model test data. This approach has provided satisfactory result for shallow water risers, but deepwater risers are likely to have higher order mode of vibration in strong currents. The present study was carried out to provide more accurate analyses of VIV phenomena, using the Finite-Analytic Navier-Stokes (FAN) numerical method in conjunction with chimera domain decomposition. The results from the study were then compared with available experimental data to assess the accuracy of the CFD predictions.



Fixed Riser | Vibrating Riser

Figure III.5: Vorticity Contours for Computational Riser Models

III.1.1.7 Project No. 471 – Assessment of Performance of Deepwater Floating Production Facilities during Hurricane Lili

The study was carried out to assess the Performance of Deepwater Floating Production Facilities during hurricane Lili using current design tools. Overall, predictions from current design tools were found to be close to the actual environmental impacts from extreme conditions on deepwater floating structures.

Figure III.6: Damage to an offshore structure during extreme event

III.1.2 INTEGRITY MANAGEMENT (IM)

The continuous increase in water depths for oil and gas production imposes significant challenges on the current available technologies. As such, MMS TA&R Program has funded research into the reliability and integrity of these new industry advancements as represented by TA&R Projects No. 536, 531, 500, and 497 below:

III.1.2.1 Project No. 536 – Compliant Vertical Access Riser (CVAR) Risk Assessment Study

The objective of the research was to conduct a risk assessment study for the new Compliant Vertical Access Riser (CVAR) concept. A risk Assessment study was carried out for two field development using two production riser casing alternatives (i.e. tubing casing and dual casing) for CVAR. The study was able to identify the risks associated with the use of CVAR and make a comparison with other proven riser solutions such as the TTR and SCRs in The US Gulf of Mexico. Overall, It was found that the risk associated with operations from a CVAR concept are similar and in some cases less than those experienced in the industry from deepwater production risers.

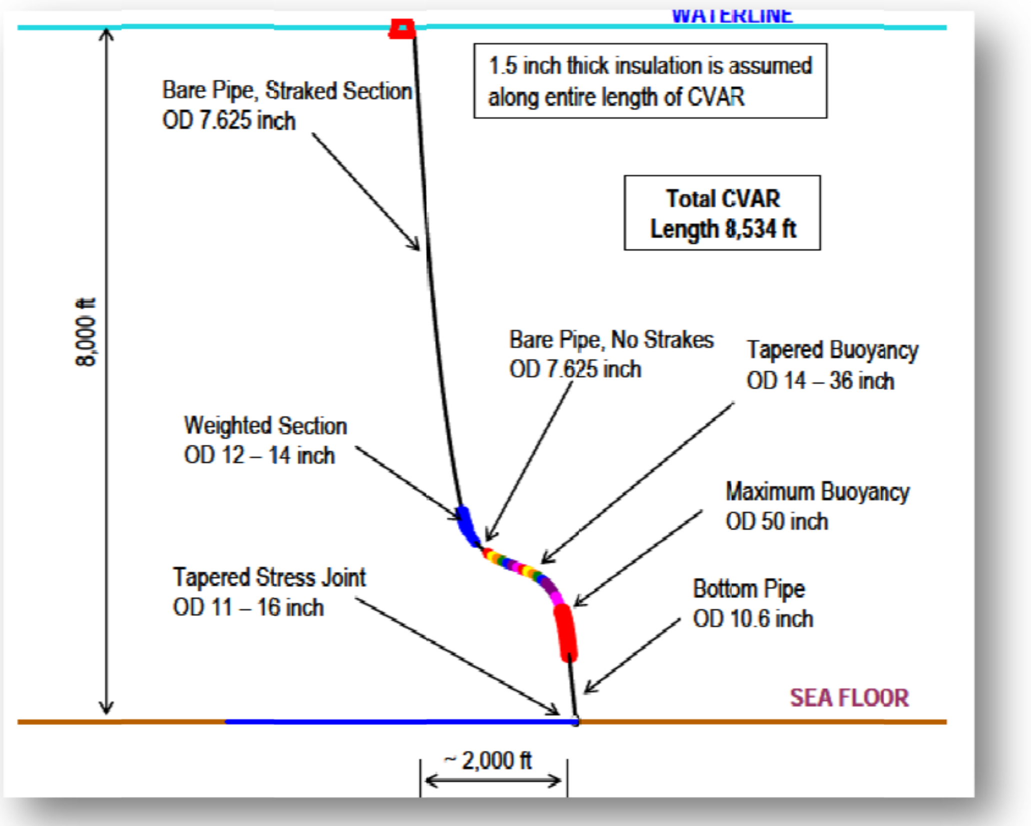
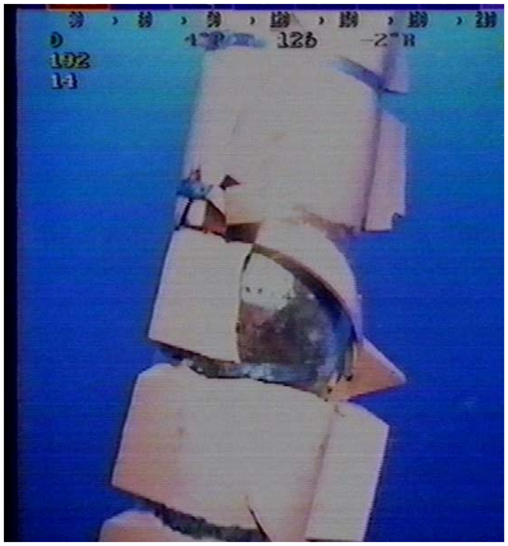


Figure III.7: Illustration of CVAR configuration

III.1.2.2 Project No. 531 – Steel Catenary Riser Integrity Management JIP

The SCRIM (Steel Catenary Riser Integrity Management) JIP was an industry-sponsored initiative from 2004 to 2008 to develop industry guidelines for the integrity management of offshore risers and interrogate current state-of-the-art and developing inspection and monitoring techniques for risers. The original scope of the JIP was limited to 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 riser and top-tension riser (TTR) systems. A consistent methodology was presented for addressing these riser systems, which served as the basis for current draft revisions of ISO 13628-12/API RP 2RD.



Strake damage

SCR Burrowing

Figure III.8: Example of Strake damage and trenching

III.1.2.3 Project No. 522 – New Methodologies for Measuring and Monitoring Hydrogen for Safety in Advanced High Strength line Pipe Steel

Structural integrity of high strength steels (in excess of 70 ksi yield strength) is affected by hydrogen. Hydrogen damage refers to the reduction in the physical and mechanical properties of a steel material due to the presence of hydrogen in the micro-structure.

Hydrogen can be introduced into line-pipe steel through welding, cathodic protection, corrosion reactions, and interaction with the fluid contained in the pipe. Research efforts in hydrogen damage have been hampered as conventional tool only measures the total effects of very large numbers of hydrogen molecules, ions, or protons, on specimen or service component. The aim of the study was to develop a non-destructive and non-contact tool to measure the diffusible hydrogen in coated steel pipe using electromagnetic techniques.

III.1.2.4 Project No. 500 - Risk Comparison Subsea vs. Surface Processing

Subsea separation and boosting is an attractive novel solution to offshore oil and gas production in the US Gulf of Mexico. The Minerals Management Service (MMS) requires that new technologies are proven to be as safe and reliable as the existing technology with respect to personnel and environmental risks. The MMS initiated this comparative risk assessment study to provide a better understanding of subsea processing technologies. No new risks to subsea oil and gas production were identified from the study that was carried out.

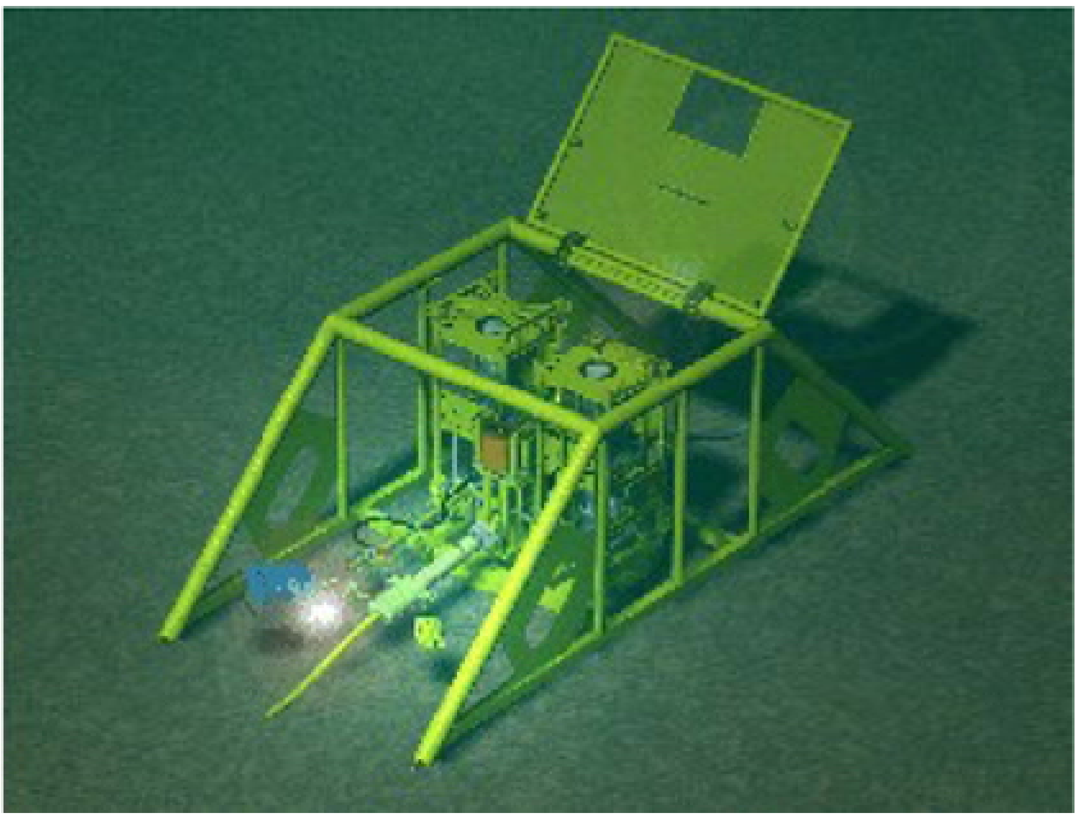


Figure III.9: Subsea Booster Station

III.1.2.5 Project No. 497 – Probabilistic Reliability and Integrity Assessment of Large Diameter Steel Compliant Risers for Ultra-deepwater

The use of SCRs for Ultra-deepwater (i.e. ~ 10,000 ft) is an emerging technology. The US Mineral Management Service (MMS) requires new technologies in the offshore energy industry to be proven as safe and reliable as existing technology. For this reason, MMS commissioned INTEC Engineering and Martec to study the reliability and integrity of SCRs in "ultra-deepwater" for US Gulf of Mexico applications.

The fatigue and extreme condition performance results from the two generic study cases (i.e. a truss spar and semi-submersible floating structures) indicated that SCR supported from appropriately designed spars and semi-submersibles is feasible in water depths up to and beyond 10,000 feet.

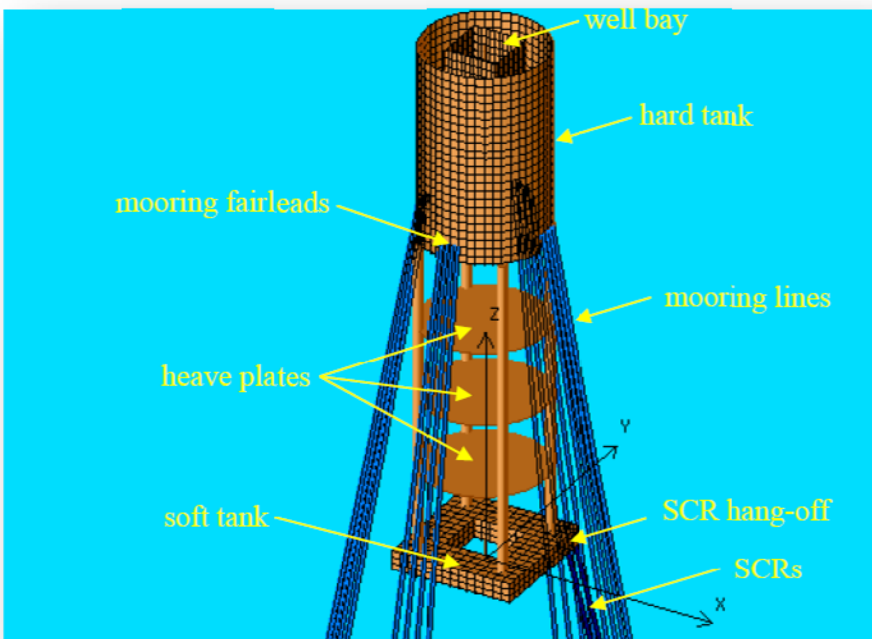


Figure III.10: A spar model

III.1.2.6 Project No. 490 – Comparative Risk Assessment for Composite Drilling and Production Risers

As offshore exploration moves into deeper waters, there is a growing interest in the use of composite production riser to replace steel risers due to the reduction in weight. The use of composite for offshore riser application has never been done in the US Gulf of Mexico and the Minerals Management Services (MMS) requires all new technologies for offshore oil and gas production to be verified as safe as existing technology. This comparative risk analysis study was carried out for a steel risers and a composite riser for use on a deepwater floating production system.

For the Composite Production Riser (CPR) analyzed, only the riser joints and pup joints were composite. The tieback connector, Stress Joint (SJ) and Tension Joint (TJ) were made from conventional steel. Overall, the risks associated with the use of composite materials on risers were found to be similar to those for a steel riser. No new risks were identified from the use of composite riser.

III.1.2.7 Project No. 487 – An Assessment of Magnetization Effects on Hydrogen Cracking for Thick Walled Pipelines

High strength steels used for transporting oil and gas are susceptible to hydrogen induced cracking. The integrity of pipelines is monitored using intelligent inspection tools one of which is the in-line inspection technology which is based on determination of localized Magnetic Flux Leakage (MFL). The magnetic saturation flux density of high-strength pipeline steel is approximately 1.9 Tesla (19,000 Gauss), while the remaining density is in the region of 1 Tesla (10,000 Gauss). Since the energy product of MFL pigging tools can easily reach 30 megaguass-oersted (MGOe) and even up to 50 MGOe, depending on the level and duration of remnant magnetization left by MFL inspection tools, steel may become more susceptible to Hydrogen Induced Cracking (HIC).

The aim of the study was to demonstrate experimentally that the magnetic induction generated by MFL inspection tools affect considerably the hydrogen content in pipeline steels (as received and cold worked) and its influence on HIC susceptibility of pipeline steels.

III.1.3 CORROSION

III.1.3.1 Project No.496 Design of Cathodic Protection Systems for Deep Water Compliant Petroleum Production Risers

Structural steel pipelines have served as the primary production product transportation mode oil and gas product transport. For deepwater production, Catenary risers often serve as a component for this transport. Technological advancements such as, deepwater fixed structures, sub-sea production units, floating production Storage, and Offshore Loading (FPSO) systems have increased the requirements for protecting structural pipelines against corrosion. This study was carried to develop a Cathodic Protection (CP) design protocol for deepwater petroleum production compliant risers.

III.2 SUBSEA RISER DESIGN

III.2.1 PROJECT NO. 622 – IMPACT OF MARINE GROWTH ON PIPELINE RISERS FOR FLOATING PRODUCTION FACILITIES

III.2.1.1 Introduction

III.2.1.1.1 Background

The current riser design standard (1998 API RP 2RD) states that only equipment in the first 150ft of the water column should be subjected to marine growth. This rationale was based on the premise that marine growth is only likely in upper portion of the euphotic zone, the region in which photosynthesis is able to occur (approximately to 660ft water depth). However, some evidence suggested that marine growth may extend much deeper in the water column than originally believed in the Gulf of Mexico (GOM).

The addition of marine growth to a riser system is considered detrimental due to the additional mass and hydrodynamic loading. The concern was that this disadvantage may translate into increased stresses in the system, decreases in fatigue performance and additional tension requirements. A previous MMS sponsored JIP gathered inspection data on facilities in the GOM from 1950 to 2000, including marine growth measurements.

III.2.1.1.2 Technical Scope

The project investigated what marine growth profiles had been observed in the Gulf of Mexico, marine growth profile affect on pipeline riser performance in terms of stress and wave-induced fatigue, and current state-of-the art technologies available for marine growth inspection, removal and mitigation. The tasks for this project were to:

- Survey industry to assess the level of marine growth experienced on facility risers in the Gulf of Mexico, levels of inspection being performed, and inspection techniques and anti-fouling measures employed;
- Assess the impact of marine growth profile on the global riser response (stress and fatigue) for a Steel Catenary Riser assuming no VIV suppression;
- Assess the impact of marine growth profile on the global riser response (stress and fatigue) for a Steel Catenary Riser, with strakes and with fairings;

- Establish what technologies are available for marine growth inspection, removal and mitigation.
- Information was compiled from industry surveys, public domain information and company internal project experience. Assessment of global riser response employed standard riser strength and wave-induced fatigue analysis methodology.

III.2.1.1.3 Study Limitations

- Survey response for marine growth profiles was limited to 5 of the 43 facilities within the GOM, so there is limited use of results for developing new design profiles.
- The deepwater case study only assessed marine growth impact on SCR performance, not TTR or flexible riser systems.
- No assessment was made of impact on VIV suppression device effectiveness.

III.2.1.2 Project Conclusions

III.2.1.2.1 Key Conclusions and Results

In summary, the results are:

- Marine growth is observed down to 2000ft water depths, much deeper than the 150ft below sea level assumed in the 1998 API RP 2RD;
- Observed marine growth thickness seems to be much less than the 1.5in assumed in the 1998 API RP 2RD, which may be attributable to the use of anti-fouling coatings;
- The additional marine fouling had limited impact on steel catenary risers (SCR) strength and wave-induced fatigue response, which is representative of the most typical deepwater riser pipeline systems;
- Deeper marine growth profiles may have more significant impact on weight-sensitive systems (such as TTRs) or systems that are fatigue-critical in the hang-off region (flexible risers), which will become more prevalent amongst deepwater applications in future years;
- Marine growth inspection and removal techniques are mature applications, with little change in the last 15 years;

The primary focus in the offshore energy industry is the development of anti-fouling coatings without tributyl tin (TBT), such as self polishing copolymer (SPC) biocidal coatings.

III.2.1.2.2 OSER Goals

This study attempted to verify the sufficiency and conservatism of marine growth design criteria and management techniques, by assessing what profiles have actually been observed with current industry practices and by analyzing the subsequent impact on riser global performance. While questions remain regarding marine growth impact on the effectiveness of VIV suppression devices and on the TTR and flexible riser systems, the project verified that observed marine growth profiles are not likely to have a significant adverse affect on the robustness of most riser systems current in water depths greater than 5,000ft.

III.2.1.2.3 Recommendations

The authors recommended:

- Development of a marine growth profile extending beyond the API RP 2RD 150 ft water depth to a depth on the order of 2000 ft, to be based primarily on measurements taken during visual inspections. Ideally, these inspection reports would include a measure of the change in marine growth between inspections.
- Further analytical studies using this new profile to assess the impact of marine growth on various riser systems (e.g. TTRs and flexible risers). The deeper marine growth profile may have more significant impact on weight-sensitive systems (such as TTRs) or systems that are fatigue-critical in the hang-off region (flexible risers).
- Assessment of the performance of anti-fouling coatings over the installed life, through collection and analysis of in-field data.

III.2.1.3 Current State of Knowledge

The recent trend in recommended practice emphasizes site-specific assessments. Although no new industry recommendations have been issued regarding the marine growth profiles for riser design, a recent API 2MET draft reports soft marine growth to 2000ft water depths.

The analysis methodology reflects industry recommended practice by API, DNV and ISO. Recent MARINTEK / SINTEF work suggests that the marine growth may have a more significant impact on effectiveness of VIV suppression devices.

There has been no major break-through in technology since the report was issued.

III.2.2 PROJECT NO. 572 – DEEPWATER RISER DESIGN, FATIGUE LIFE AND STANDARD STUDY REPORT

III.2.2.1 Introduction

III.2.2.1.1 Background

Steel Catenary Risers (SCRs) are a relatively inexpensive solution for production and export of offshore hydrocarbons from floating production systems. The first SCRs were 12 inch export SCRs installed in 1994 on Auger tension leg platform (TLP). The first Flexible pipe was used as a kill and chock line in 1976 and ever since has been developed for riser function in different parts of the world. Flexible Catenary Risers (FCRs) are generally more expensive than SCRs and have diameter and pressure limitations. The two riser systems are in many cases faced with similar design challenges. As SCRs have only been in use for slightly more than a decade, it will take more time to develop a data base from which to draw conclusions with respect to the actual critical failure modes. The proprietary approach taken by flexible line manufacturers also limit the ability to identify certain aspects such as the fatigue life and long-term thermal degradation. The aim of the project was to assess the current industry practice for design methodology and reported failures in an effort to provide a useful input for riser design, analysis, future studies and regulatory guidance.

III.2.2.1.2 Technical Scope

The scope of the project includes the following:

- Identification of critical areas of SCR and FCR design through an industry work shop and a review of past riser system failure data base.
- A review of existing regulations and current industry practice for deepwater infield and export SCR and FCRs designs.
- Assessment of accuracy on past riser monitored performance data versus predicted FEA model response and potential impact on safety factors.

III.2.2.1.3 Study Limitations

- The failures considered in the study were only limited to the significant deepwater SCRs and FCRs failures.

III.2.2.2 Project Conclusions

III.2.2.2.1 Key Conclusions and Results

The following are key conclusions from the study:

- It was concluded that a general guideline for the offshore energy industry should not be too prescriptive, but instead illustrate general guiding principles.
- A better SCR and FCR fatigue guidance and Certified Verification Agent (CVA) scoping is needed.
- There is a need for a better rationalization of cathodic protection for SCR strakes and touchdown regions
- The central MMS damage/repair database is useful, but was not designed to be a deepwater riser damage assessment tool.
- The Ongoing review of recommended practices should involve deepwater riser industry and regulating specialists.
- The update of the key guidance areas should also include Limit State Design (LSD) and Integrity Management (IM).

III.2.2.2.2 OSER Goals

This study has assessed the current industry practices, failures and regulatory requirements for analysis and design, of pipeline risers on floating structures. Incorporating the recommendations from the study in recommended practices and standards for SCR and FCR will provide a better design and integrity management knowledge to both designers and operators. This is inline with the OSER program goals part of which is the evaluation of technological challenges associated with the entire life cycle of offshore oil and operations.

III.2.2.2.3 Recommendations

The authors recommended:

- Continuance of the flexibility given to the industry to provide its own detailed design solutions based on higher Recommended Practices (RP) and CFR guidance.
- The oversight and the involvement of deepwater riser industry and regulatory specialist in the ongoing update of relevant recommended practices such as API RP 2RD.

- The inclusion of on Limit State Design (LSD) and Integrity Management (IM) in the ongoing key areas for guidance update of recommended practices.
- Provision of clearer guidance on cathodic protection to designers and operators in recommended practices and standards.
- The development of separate S-N curves for simulating sour service conditions in carbon steel pipes.
- The use of full size specimens, incorporating the service condition where possible for better fatigue understanding.
- The development and inclusion of S-N fatigue curves for flexible pipe tensile and pressure armor layers in riser design recommended practices and standards.
- The use of Frequency Domain (FD) analysis for initial riser design analysis and evaluation and Time Domain (TD) analysis during detailed engineering on complex riser system with significant non-linearity.
- Riser monitoring as a voluntary industry practice to help provide valuable information for riser IM.

III.2.2.3 Current State of Knowledge

Fatigue related issues at the TDZ are currently approached at design with the use of a higher stress intensity factor for the SCR TDZ. The material for the TDZ during fabrication is kept the same with other parts of the SCR but techniques to improve the fatigue performance at welds such as improved pipe fit-up for best tolerance and ground flushing of weld are used for the TDZ.

III.2.3 PROJECT NO. 510 – SEAFLOOR INTERACTION WITH STEEL CATENARY RISERS

III.2.3.1 Introduction

III.2.3.1.1 Background

Damage to an SCR around the touch down zone due to soil-pipe interaction is an important fatigue issue as oil and gas production moves into deeper waters. Current analyses have shown fatigue damage to be sensitive to seafloor stiffness which at present cannot be estimated with great reliability. While linear elastic seafloor models have provided an insight into seafloor-riser interactions, full scale models tests have shown that the problem involves complex non-linear processes for risers. The study aims to develop a model based on soil-riser interaction comprising of a linear elastic pipe supported by non-linear springs.

III.2.3.1.2 Technical Scope

- The technical scope of the project includes the following:
- A review of previous work on riser-soil interaction.
- Development of a non-linear spring model for riser-soil interaction taking into account the effect of initial plastic penetration into the seafloor, non-linear soil stress-strain behavior, finite tensile strength of the seafloor and separation of the riser from the seafloor.

III.2.3.1.3 Study Limitations

The following are some of the limitation of the developed model:

- The soil resistance (P) versus deflection (y) model based on spring stiffness has not been validated through comparisons with laboratory or field data.
- Only vertical riser motions were accounted for in the model, lateral riser motions though usually not significant were not considered. Lateral response or the riser may become important during extreme offset in the out-of-plane direction.
- The (P-y) model did not account for soil stiffness degradation as a result of cyclic loads.
- The developed model also did not account for alterations in the P-y curve due to cyclic loads.

III.2.3.2 Project Conclusions

III.2.3.2.1 Key Conclusions and Results

SCR technology is a proven solution and an attractive solution to oil and gas production from deeper water. A better understanding of SCR in the touch down zone is vital for future application of SCR in ultra-deepwater. Tools such as the model from this study when verified will form an important tool for assessing the reliability and safety of SCR in deepwater and future ultra-deepwater applications.

III.2.3.2.2 OSER Goals

SCR technology is a proven solution and an attractive solution to oil and gas production from deeper water. A better understanding of SCR in the touch down zone is vital for future application of SCR in ultra-deepwater. Tools such as the verified model from this study will be useful for assessing the reliability and safety of SCR in deepwater and future ultra-deepwater applications.

III.2.3.2.3 Recommendations

The authors recommended:

- Validation of the model through a comparison with laboratory test basin measurements.
- Incorporation of the soil stiffness degradation due to cyclic loads into the developed model

III.2.3.3 Current State of Knowledge

The behavior of the soil and interaction with the riser is complicated and not well understood. The conventional practice is to represent the seabed with a simplistic model which does not include any aspects of the real physical behaviors of the soil. The model is a flat contact surface with linear elastic stiffness. Riser design and analysis software such as MCS Kenny's Flexcom and Orcina's Orcaflex have been upgraded by incorporating non-linear soil modeling capability based on spring models.

III.2.4 PROJECT NO. 509 – INTERSTITIALLY INSULATED PIPE

III.2.4.1 Introduction

III.2.4.1.1 Background

Increase in oil and gas consumption has driven offshore production into deeper waters. Crude oil often contains a type of wax that begins to form solid paraffin deposits on the inner surface of the pipe when oil temperatures reach the paraffin cloud point (around 68 deg C). At current seafloor depths, pipe insulation is essential to avoid these flow assurance issues. Crude production temperatures are typically above 70 deg C to maintain the inner wall temperature above the paraffin temperature point.

Several insulation techniques have been developed to overcome thermal issue like the addition of low conductivity materials and coatings on the external pipe surface. However, these techniques often have severe limitations such as damage due to large hydrostatic pressure differential and installation loads. This study was carried out to investigate effects of thermal insulation using one or more layers of a wire screen as an interstitial material within the annulus of a coaxial pipe.

III.2.4.1.2 Technical Scope

The project was carried out in three phases. The first phase of the project was completed in December 2005 under the following work scope:

- Development of analytical expressions for predicting and comparing thermal resistance performance against the commercially available technology.
- Experimental investigation to determine the level of thermal resistance achievable with wire screen technology.
- Discussion of results obtained from the study.
- The second and third phases of the project were carried out in June 2007 and it involved the development of analytical macro and micro contact resistance model for performance prediction and the testing of prototype pipe for actual thermal performance characterization.

III.2.4.1.3 Study Limitations

- There were uncertainties on the deformation behavior of the screen wire mesh and its interaction with the intermediate liners under compression.
- Analytical modeling was done using finite element. Finite element analyses will introduce some errors since the shape of the part and the material behavior are approximated
- The effect of compression on the thermal conductivity of the insulation material used is unknown
- One of the main insulation agents for the new insulation technology is air. A severe drawback with using air is moisture. The air gap that the wire mesh creates could pose a problem if air is allowed to reach the dew point temperature

III.2.4.2 Project Conclusions

III.2.4.2.1 Key Conclusions and Results

In summary, the results are:

- The concept of using a wire screen as an interstitial insulation was found to dramatically increase the thermal resistance when compared with a bare pipe section.
- The developed macro and micro contact analytical resistance models were used to predict the thermal performance of an interstitially insulated coaxial pipe system which contained a wire screen.
- By developing an analytical model for a single layer screen wire insulation, the thermal conductance or resistance could be predicted for any given contact pressure.

III.2.4.2.2 OSER Goals

Interstitially insulated coaxial pipe is a novel solution to flow assurance issues associated with deepwater and ultra-deepwater oil and gas production. Although qualification of this new technology for fabrication and installation has not been done, the study was able to demonstrate an increase in thermal resistance through an analytical model and experiments. Thermal insulation of pipes by this method will increase the tolerance of the pipe insulation to installation and service loads. This is inline with the OSER goals which aims to verify emerging technologies in terms of reliability, operational safety and environmental protection.

III.2.4.2.3 Recommendations

The author recommended:

- Further study into the over-predictions by the analytical model at lighter pressure.
- Further experimental investigations are needed to quantify the effects of the design on thermal performance.

III.2.4.3 Current State of Knowledge

The most common type of external thermal insulation coating for offshore riser application is multi-layered syntactic polypropylene system. For pipe-in-pipe risers and pipelines, Aspen Aerogels has been used as pipe insulation material. There is no known application of the pipe insulation technique investigated in this study.

III.2.5 PROJECT NO. 494 – NEW TOUCH DOWN ZONE (TDZ) SOLUTIONS FOR SCRS – DEVELOPMENT AND QUALIFICATION OF ALTERNATIVE DESIGN SOLUTIONS

III.2.5.1 Introduction

III.2.5.1.1 Background

The use of SCR for offshore oil and gas production has significantly increased since its first use in the US Gulf of Mexico (GOM) as an export riser on the Auger TLP in 1993. In recent years SCR design has been used in some regions with semi-submersible and tanker based Floating Production Storage and Offloading (FPSO) units, which in some cases required significant changes in hull design.

The use of SCR with floating unit in deepwater and ultra-deepwater is challenged by high fatigue damage estimated in offshore and onshore welds at the SCR touch down zone (TDZ). The industry has evaluated alternative approaches such as construction measures, operational measures, improved understanding of SCR behavior at TDZ, design changes at TDZ, and change in SCR shape or material, to further increase SCR application and improve riser integrity against cyclic loading. In some cases, results from these measures have been implemented. Presently, none of the alternative design has found applications due to lack of qualification data for these solutions. This JIP study was carried out to increase the Technological Readiness Level (TRL) of these design solutions. The qualified solutions includes, titanium segment, thick light weight coating, steel riser with integral threaded connectors, and steel riser section with upset ends.

III.2.5.1.2 Technical Scope

The JIP study was carried out under the following work scope:

- Comparative assessment of alternative TDZ design solutions
- Case study analyses aimed at estimating the design changes required at the SCR touch down zone for each selected solution

- Design development and qualification assessment aimed at improving the overall understanding of each solution
- Qualification testing and analysis aimed at under taking manufacturing or application of solutions.

III.2.5.1.3 Study Limitations

The following are some of the limitations of the study:

- The selected field developments, on which the qualification was based on, were generic.
- Application and testing for the thick light weight coating solution was limited to 8.75" due to limitation in manufacturing capabilities.
- High strength steels for the integral threaded connector solution have not been tested for corrosion-fatigue behavior.
- The study was limited to only the feasible TDZ alternative solutions.

III.2.5.2 Project Conclusions

III.2.5.2.1 Key Conclusions and Results

In summary, the conclusions were:

- The JIP was able to increase the technology readiness level (TRL) of four alternative design solutions undertaken to solve the offshore energy industry concern with SCR fatigue performance at TDZ by successfully qualifying all four alternative designs.
- The JIP was able to demonstrate the feasibility of installation of SCR TDZ sections with proposed solutions using J-lay installation.
- Final adoption of the qualified riser TDZ fatigue solution will provide high value by improving the reliability of SCRs and a potential to provide savings in overall platform design and riser integrity management program.

III.2.5.2.2 OSER Goals

One of the significant integrity issues associated with deepwater application of SCRs is fatigue damage at the TDZ. The JIP successfully qualified the proposed new design solutions for SCR touch down zones aimed at improving the fatigue life. Increasing the fatigue life of an SCR is a technological challenge necessary to maintain the integrity of the riser system throughout the design life. This is inline with OSER goal of evaluating the technological challenges associated with the entire life cycle of offshore oil and gas operation.

III.2.5.2.3 Recommendations

- The case study was only carried for generic fields in the Gulf of Mexico and West of Africa, improvement in fatigue life and associated cost will vary for different solutions and depend on a number of field specific parameters.
- For the integral threaded connector solution, additional qualification effort is required for corrosion-fatigue behavior of high strength steel.
- Some companies based on internal evaluation procedures may consider a need for additional testing or analysis.

III.2.5.3 Current State of Knowledge

Fatigue related issues at the TDZ are currently approached at design with the use of a higher stress intensity factor for the SCR TDZ. The material for the TDZ during fabrication is kept the same with other parts of the SCR but techniques to improve the fatigue performance at welds such as improved pipe fit-up for best tolerance and ground flushing of weld are used for the TDZ. None of the qualified solutions for the TDZ is known to have been applied on any new field development.

III.2.6 PROJECT NO. 481 – CFD SIMULATION OF A RISER VIV

III.2.6.1 Introduction

III.2.6.1.1 Background

Vortex Induced Vibration (VIV) is an important fatigue issue for deepwater riser systems. VIV can produce a high level of fatigue damage due to severe currents in subsea riser over a relatively short period of time. Oil and gas exploration has also moved into even deeper waters (near 10,000 ft) making it desirable to develop advanced computational fluid dynamic (CFD) tools that can provide reliable prediction of riser VIV in deepwater environment.

Deepwater current profiles tend to be more complex than in shallow water. Majority of the currently available software tools are based on empirical formulas that rely heavily on model test data. Although this approach provides satisfactory VIV predictions for shallow water risers where their length to diameter ratio (L/D) is fairly small, and model tests could be easily carried out to provide input data and verification, deepwater risers are likely to have higher order modes of vibration in strong currents.

The present study was carried out to provide more accurate analyses of VIV phenomena, using the Finite-Analytic Navier-Stokes (FAN) numerical method in conjunction with chimera domain decomposition. The results from the study were then compared with available experimental data to assess the accuracy of the CFD predictions.

III.2.6.1.2 Technical Scope

The study was carried out under the following work scope:

- Development of modal solver for riser finite element motion equation;
- Development of direct solver for riser finite element motion equation;
- Simulation of 2D and 3D flow past riser;
- Validation of results from FANS simulation with experimental data;
- Comparison of FANS results with numerical results obtained by commercial software.

III.2.6.1.3 Study Limitations

3D flow simulations were limited to length to diameter ratios of 3 and 9, while realistic ratios for deepwater risers are over 1000. This limitation was imposed by computer processing restrictions.

CFD results are compared to experimental data derived from model tests, which were not described in the study report. While using experimental data was necessary due to the scarcity of any operational data, successfully gathering meaningful experimental data for high Reynolds numbers is often challenging due to a variety of influencing factors such as end conditions, free-stream turbulence level, and riser roughness. Evidence of these factors is evident in the data scattering, but it is unclear how this uncertainty was addressed in the study.

III.2.6.2 Project Conclusions

III.2.6.2.1 Key Conclusions and Results

In summary, the results are as follows:

- The study research in general was able to demonstrate that the FAN model is capable of long riser time domain VIV simulations and provided valuable insights on long riser VIV phenomena.
- The 2D flow field around a fixed and a vibrating riser was simulated and compared to the flow field predicted by Huse's empirical formula which is based on experimental data. The simulation results show good agreement which confirmed the effectiveness of the FANS model and data grids.
- The study was also able to show that for long marine riser, the maximum VIV response is near the riser bottom where the effective tension is a minimum. It also demonstrated that VIV response could be over-predicted if non-linear damping is not considered appropriately.

III.2.6.2.2 OSER Goals

Vortex Induced Vibration is an important fatigue issue in the design of deepwater risers. This study was carried to improve the accuracy of deepwater riser VIV predictions. A better accuracy in deepwater VIV prediction will promote better deepwater riser design and riser integrity assessment. This is inline with the OSER goals of investigating the techniques to best assess, retain or restore the integrity of aging offshore assets.

III.2.6.2.3 Recommendations

The author recommended:

- More investigation into riser high mode VIV under strong current and high Reynolds number
- More investigation into the effect of VIV suppression devices, such as fairings and strakes
- More investigation into riser VIV in complex current condition such as submerged current or bottom current.

III.2.6.3 Current State of Knowledge

Two additional projects were to follow this study (TA&R Projects No. 483 and 521), but these projects were both cancelled. This particular method was further developed by the principal investigators to assess riser VIV fatigue using CFD.

III.2.7 PROJECT NO. 471 – ASSESSMENT OF PERFORMANCE OF DEEPWATER FLOATING PRODUCTION FACILITIES DURING HURRICANE LILI

III.2.7.1 Introduction

III.2.7.1.1 Background

Major hurricane activity (hurricanes Category 4 or worse) crossing the central and western portion of the GOM's offshore Oil and Gas developed region may result in significant damage and/or destruction to offshore oil and gas facilities and pipeline. Based on hundreds of industry damage assessment reports resulting from previous storms, MMS recognized the need to analyze damage assessment reports in order to determine the type, cause and extent of damage and to provide guidance for improving facility and pipeline integrity/design to reduce potential damage from future GOM hurricanes.

Hurricane Andrew in 1992 resulted generated extreme met-ocean conditions in excess of the design standards of the time resulting in significant damage to offshore structures, and in some case failures to 27 steel jackets. After Hurricane Andrew, the offshore energy industry and government significantly improved the design reliability of oil platforms. Hurricane Lili in 2002 provided an opportunity to validate the extreme response of offshore structures under the revised design practices.

III.2.7.1.2 Technical Scope

The project collected and assessed information on the performance deepwater production facilities in the US Gulf of Mexico that were impacted by Hurricane Lili in 2002, to provide further insight into critical design issues and develop recommendations for improvement in design and operational practices for deep water floating production installations. The work scope for the project comprised the following:

- Identify the deepwater facilities closest to Lili's track;

- Collect and assess any observed damage to the identified units, in terms of significance and potential causes;
- Determine how environmental conditions and facility response related to design limits (i.e. did the environmental conditions approach the design environment limits (i.e. did the facility response stay within design limits?);
- Assess any bias in development of design environmental conditions, based on the new data collected during Lili;
- Assess any bias in the design response / performance models;
- Summarize the key technical challenges related to predicting the global performance of deepwater floating production facilities, and assess if the data collected during Lili has significantly increased knowledge on these issues.

III.2.7.1.3 Study Limitations

Limited monitoring data was available for vessel motions and tendon tensions due to failure of monitoring systems. The data available for three of the seven units near Hurricane Lili's path were incomplete. A contributing factor for this occurrence was that the units were evacuated during hurricane Isidore and powering of the monitoring system had not been restored (or failed) during the hurricane.

The criteria used for assessing if the platforms were deepwater and their closeness to Lili's path was not discussed.

III.2.7.2 Project Conclusions

III.2.7.2.1 Key Conclusions and Results

In summary, the results are:

- Of the Seven units that were assessed to be close to Lili's path, consisting of 1 spar and 6 tension-legged platforms: Genesis Spar; Typhoon; Morpeth Allegheny; Jolliet; Brutus; and Prince TLP. Typhoon was the unit closest to Lili's path and subjected to the most severe environmental conditions.
- In general there was no damage to structural members. Inspection data indicated damage to secondary structures located in the air gap such as ladders and boat landings (up to 55 ft above sea level). No evidence of air gap loss was found.

- The hindcast study and measurements obtained for wind (for Brutus) and of current (for Genesis) suggests the environmental conditions during Lili were sufficient to test the response of Typhoon, Brutus and Genesis relative to their relevant design events.
- High quality buoy data provided the best indication of winds and waves during Lili. Ocean weather's hindcast model provided an accurate representation of the data measured at the buoys. The measurements obtained from the production units for environmental conditions were disappointing. No wave measurements were obtained from all the production units examined.
- Detailed analysis of the monitoring data suggested that predictions based on the current design practices were reasonably close to measurements, with an overall conservative bias in the design models.
- VIV and VIM were assessed to have less effect on the overall tendon tension for Brutus and Typhoon.
- The Turbulence closure model in conjunction with ADCP reliably predicted maximum surface current velocity to not be of concern for the units continuing operations.

III.2.7.2.2 OSER Goals

The research has assessed the performance of deepwater production facilities during extreme conditions such as a hurricane using the current design tools to identify critical design issues and develop recommendations. Overall, current design predictions were close to the actual impacts of extreme conditions on deepwater floating structures. This is inline with goals of the OSER program which is concerned with the evaluation of the technological challenges associated with the entire life cycle of offshore energy operations.

III.2.7.2.3 Recommendations

The author recommended:

- A review of the procedures for securing critical equipment that takes into account major environmental conditions such as hurricanes.
- Investigation of the impact of hurricane Lili on components which have been subjected to previous major environmental conditions.
- It was recommended that the offshore energy industry work diligently in applying tools and expertise to achieve competence in modeling VIV and VIM to reduce undue operational costs.

- A benchmark of computer programs used for predicting motions, tendon/mooring load and riser response similar to pushover analysis of platforms was recommended.
- It was recommended that the economic benefits of design capable of operating during high currents be emphasized.
- A coordinated effort to collate information and develop a risk based approach to the design and integrity management of TLPs and risers worldwide was recommended.

III.2.7.3 Current State of Knowledge

Significant improvement in design and assessment standards accrued from JIPs, Universities, R &D work within oil companies and by studies and workshop supported by the MMS, API and other organizations has resulted in an improvement in the reliability of platforms designed after the mid 1970s and a more rational risk based approach to the integrity management of the older platforms designed prior to the mid 1970s.

The first edition of API RP 2A was issued in 1969 and its ninth edition in 1979. Hurricane Andrew provided evidence of the increased reliability of fixed platforms designed after the mid seventies. Recent revisions to API-RP 2A include the following:

- API RP 2A WSD, Twenty First Editions, December 2000 – Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms, Working Stress Design
- API RP 2A LRFD, First Edition, July 1, 1993, Reaffirmed May 16, 2003 – Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms, Load and Resistance Factor Design.

API RP 2A LRFD is an improved approach to structural design which takes into account the possible uncertainties in the applied loads and component resistance.

III.3 INTEGRITY MANAGEMENT

III.3.1 PROJECT NO. 536 – COMPLIANT VERTICAL ACCESS RISER (CVAR) RISK ASSESSMENT STUDY

III.3.1.1 Introduction

III.3.1.1.1 Background

Compliant vertical access riser (CVAR) presents a new alternative for direct vertical access (DVA) to subsea wells from the deck of a floating production unit (FPU). Some advantages associated with the riser system include a reduction in riser payload and dry tree completion in deepwater and ultra-deepwater. The CVAR is directly connected to the hull of the FPU at its top, and does not require riser top tensioning system or production jumpers used for top tensioned riser (TTR) designs. Direct connection of the CVAR requires a change in riser design from a conventional vertical riser (like the TTRs where the tensioner system accommodates relative motions of riser and hull) to a compliant configuration. The compliant shape of the CVAR system permits the wellheads to be offset a considerable distance from the FPU.

Elimination of the riser top tensioning system results in direct transfer of loads from the CVAR to the hull of the FPU. The CVAR design also presents a riser system with significant variations in cross section along the length of the riser. The possible sources of failure of the riser system and their consequences will also vary along the riser length. CVARs have not been used in the US Gulf of Mexico. The only known attempt was a conceptual study for its possible use for the Magnolia TLP project.

III.3.1.1.2 Technical Scope

The objective of the project was to assess the risk associated with the use of two production casing alternatives (i.e. tubing casing and dual casing) for CVAR on two field developments. The technical scope of the study is summarized below:

- Conduct a conceptual design analysis on two possible CVAR production casing designs for two different field developments in the US Gulf of Mexico.

- Undertake a qualitative risk assessment for the two CVAR production casing designs during installation, production and well operation.
- Carryout a comparative risk assessment between a CVAR, TTR and SCR designs.

III.3.1.1.3 Study Limitations

The risk assessment study was only carried for the conceptual phase of subsea riser design.

III.3.1.2 Project Conclusions

III.3.1.2.1 Key Conclusions and Results

In summary, the results are:

- Strength analysis for the two CVAR production casing designs (i.e. tubing casing and dual casing) showed that the maximum tension and Von Mises stresses occur at the hang-off position, while the minimum riser tension occurred at the transition (buoyancy) region. A fatigue analysis carried out found the CVAR configuration to be insensitive to first order and second order vessel motions. From the interference analysis, it was found out that the riser can be designed to allow for minimal light contacts during the maximum loop current. The critical area for riser to riser interference was found to be the upper 500 to 1000 ft.
- The qualitative risk assessment for the conceptual design of the two CVAR design showed that the riser is made up of components that have been used in other subsea riser designs and is faced with similar risks during installation, operation and well work over. The study was also able to identify the risks associated with the CVAR design and propose possible risk reduction measures.
- A comparison of the CVAR, and the TTR designs showed that the CVAR requires lesser number of different primary load carrying members, thus reducing the total number of potential failure modes associated with the primary load carrying member design. The higher number of ancillary components on the CVAR makes it susceptible to failure due to dropped objects. Overall, the risk associated with operations from a CVAR concept are likely to be similar or less than those experienced in the offshore energy industry from deepwater and ultra-deepwater production risers.

III.3.1.2.2 OSER Goals

CVAR offers important benefits in terms of the possibility for dry tree completion and DVA to deepwater and ultra deepwater wellheads. The study was able to identify and compare the risks associated with the use of the new riser design with other known and proven riser solutions (i.e. TTRs and SCRs) in the US Gulf of Mexico. The study was able to verify that the use of CVAR does not present any risks different from those associated with DVA risers and that the risk associated with its use can be handled in a similar way to those associated with SCRs and TTRs. The risk assessment study served as an independent verification of this emerging technology in terms of reliability and operational safety.

III.3.1.2.3 Recommendations

- The risk assessment study was carried at the conceptual stage of design, for potential use of the CVAR design it is recommended that risk assessments be carried during other phases of design to identify any new risks.
- The new riser concept has similar component to SCRs and TTRS, lessons learned from the design, fabrication and installation of TTRs and SCRs in the US Gulf of Mexico will be very useful for the new riser design concept.

III.3.1.3 Current State of Knowledge

Compliant Variable Access Riser (CVAR) is an attractive deepwater riser solution that allows direct vertical access to a subsea well head. A conceptual study was carried out for CVAR during the Magnolia TLP project in the US Gulf of Mexico but was not used in the actual field development.

III.3.2 PROJECT NO. 531 – STEEL CATENARY RISER INTEGRITY MANAGEMENT JIP

III.3.2.1 Introduction

III.3.2.1.1 Background

At the launch of the JIP, there was no widely-accepted systematic approach for the risk assessment and development of appropriate risk-based integrity management strategy for steel catenary riser (SCR) systems. Previous industry initiatives had focused on 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.

III.3.2.1.2 Technical Scope

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 riser and top-tension riser (TTR) systems. A consistent methodology was presented for addressing these riser systems.

III.3.2.1.3 Study Limitations

- 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.

Flexible risers were not included in the expanded scope of this JIP. At the time, flexible risers were not generally in use for deepwater Gulf of Mexico developments, and the integrity management of flexible risers had been investigated in previous JIPs.

III.3.2.2 Project Conclusions

III.3.2.2.1 Key Conclusions and Results

In summary, the results are:

- An easily implemented, transparent risk assessment methodology was developed, applicable to any engineered system and capable of being adapted to any corporate or regulatory standard.
- Current state-of-the-art and developing inspection and monitoring techniques for steel Catenary risers were thoroughly interrogated.
- Exhaustive failure mode lists were compiled with example integrity management measures for each riser system.

III.3.2.2.2 OSER Goals

Risk-based integrity management of SCRs had lagged behind approaches developed for other safety-critical assets such as pipelines; this JIP addressed this gap. Exhaustive lists of potential riser hazards were compiled, addressing fabrication to end of life. The JIP also thoroughly investigated the industry state-of-art and emerging technologies for the retention of riser structural integrity throughout the asset's lifecycle, particularly with regards to inspection and monitoring capabilities.

III.3.2.2.3 Recommendations

The authors recommended:

- A risk-based, quasi-qualitative approach for riser integrity management, due to the scarcity of quantitative failure statistics and multivariate failure relationships.
- Integrity management should be treated as a dynamic, continuous process, with risk-based inspections and periodic integrity reviews. Design basis assumptions should be verified over the riser life.
- Reviews should also be conducted to confirm that the integrity management plan is being implemented as planned. Integrity management plans should also be reviewed periodically to confirm that the plan meets the most recent regulatory and corporate standards, and to assess the overall effectiveness of the plan at retaining the integrity of the asset.

A holistic approach to integrity management should be investigated, including not only risers and flow lines but also umbilicals and subsea equipment.

III.3.2.3 Current State of Knowledge

The risk-based methodology developed still reflects much of industry best practice for riser integrity management, and served as a basis for the riser integrity management chapter within the latest draft revision ISO 13628-12 / API RP 2RD.

Industry momentum has been towards adopting a holistic approach to subsea integrity management. JIPs are underway to address SURF (Subsea, Umbilical, Riser and Flowline) Integrity Management.

III.3.3 PROJECT NO. 522 – NEW METHODOLOGIES FOR MEASURING AND MONITORING HYDROGEN FOR SAFETY IN ADVANCED HIGH STRENGTH LINE PIPE STEEL

III.3.3.1 Introduction

III.3.3.1.1 Background

Increase in the demand for oil and gas worldwide has resulted in the development of high-pressure gas transmission lines with the greatest possible transport efficiency while reducing the cost of pipeline construction and operation. Higher strength steels such as the X80 have been developed to provide better transport efficiency through larger diameter pipelines with a reduction in wall thickness. Hydrogen cracking is a major problem associated with in-service pipelines, especially high strength steel pipe. Hydrogen from welding, cathodic protection, and corrosion can affect the mechanical and physical properties of high strength steel.

There are many non-destructive tools such as eddy currents, magnetic flux leakage, ultrasonic etc which are available in the market for crack, surface and corrosion inspections. These non-destructive tools are necessary to guarantee pipe integrity, however these tools do not assess diffusible hydrogen until significant cracking has occurred. This study is a new approach to monitor diffusible hydrogen content before significant defect arises.

III.3.3.1.2 Technical Scope

The study was divided into the following work scope:

- A review of the effect of hydrogen on steel.
- Study of the currently available non-destructive Hydrogen sensor tools.
- Develop a non-destructive and non-contact, electromagnetic analysis tool based on experimental observation for the determination of the hydrogen content in coated X80 line-pipe steel specimen.

III.3.3.1.3 Study Limitations

The primary focus of the study was on high strength steel grades, further experiment will need to be carried out for other grades of steel.

III.3.3.2 Project Conclusions

III.3.3.2.1 Key Conclusions and Results

In summary, the results are:

- The study was able to show that hydrogen contents can be measured using electromagnetic techniques under very specific conditions.

III.3.3.2.2 OSER Goals

High strength steels are effective solution for transporting oil and gas through larger diameter pipeline at reduced cost and weight. Hydrogen cracking is a major integrity problem associated with in-service pipelines, especially high strength steel pipelines. A non-destructive and non-contact tool for assessing the hydrogen content of steel will be useful in monitoring the diffusible hydrogen content of steel before defect arises. This is inline with the OSER goals of investigating the techniques to best assess, retain or restore the integrity of aging offshore assets.

III.3.3.2.3 Recommendations

The authors recommended:

- More work to create calibration curves for various line-pipes.

III.3.3.3 Current State of Knowledge

The current inspection tools such as ultrasonic, radiography, eddy currents etc specified in most industry standards cannot be used to monitor the hydrogen content of steel pipes. Detection is only possible after a defect has been created. There has been no known industrial application of the technique developed from this study.

III.3.4 PROJECT NO.500 – RISK COMPARISON SUBSEA VS SURFACE PROCESSING

III.3.4.1 Introduction

III.3.4.1.1 Background

Oil and gas production from deeper waters has increased the need to provide energy to well stream to reach the treatment facilities. Potential for slugging and challenges related to managing large amounts of produced water at the surface is also an important challenge. Subsea processing is an attractive solution to some of the problems highlighted above. Subsea separation can be either two or three phase separation, followed by pressure boosting to dispatch the liquid phase(s) to the receiving facilities. Subsea separation could have a positive effect on flow assurance, including hydrate formation and internal corrosion protection which results from produced water in combination with gas in the production fluid.

Despite the huge advantages associated with the technology, there are uncertainties related to the performance of these systems due to limited operational experience. Also, subsea processing requires an extension of the existing technologies, and increased reliance on remote operations and control systems. These factors and other factor are responsible for the interest in a risk assessment and risk comparison of subsea versus surface based processing.

III.3.4.1.2 Technical Scope

The study focused mainly on subsea boosting and subsea separation. The scope of the study includes:

- Detailed evaluation of available subsea processing technologies.

- Assessment of the risk related to subsea processing equipment during the entire life of a field development.
- Comparison of the risks associated with subsea processing and a conventional base case.

III.3.4.1.3 Study Limitations

The risks considered were mainly for subsea separation and subsea boosting. Other subsea technologies such as subsea injection and subsea compression were examined to a much lesser detail.

The risk assessment was focused mainly on personnel and environmental risks. Risk associated with loss of loss of production, system maintenance, retrieval and repair were not included in the assessment.

III.3.4.2 Project Conclusions

III.3.4.2.1 Key Conclusions and Results

In summary, the study was able to show that:

- The risks associated with subsea processing were found to be in many ways similar to conventional surface processing.
- Personnel risk exposure reduced as a result of moving more of the process equipment to the seabed.
- Environmental risks due to small hydrocarbon release were found to have higher frequency of occurrence compared with the conventional subsea tieback.
- The study was able to demonstrate that there may be significant benefits to applying subsea processing such as longer tiebacks, utilization of existing infrastructures, and exploitation of marginal fields.

III.3.4.2.2 OSER Goals

Subsea processing is an attractive novel solution to offshore production. The study was able to show that the risks associated with subsea processing are similar to those for surface processing. There were no new risks identified with respect to offshore production as a result of the novel technology. This meets the goal of the MMS which requires an independent verification of emerging technologies (e.g. new materials and practices) in terms of reliability, operational safety and environmental protection.

III.3.4.2.3 Recommendations

The authors recommended:

- The risk associated with the use of subsea processing will vary for different field developments based on design, function and operation. A separate study will need to be carried out to identify risks associated with the use of subsea processing for a new field development.
- In-spite of the benefits associated with subsea processing, limited operational experience is available. Decision process for subsea processing should consider life cycle costs.

III.3.4.3 Current State of Knowledge

Subsea separation and boosting has been applied in the US Gulf of Mexico. An example is in the Shell Perdido field development US Gulf of Mexico.

III.3.5 PROJECT NO. 497 – PROBABILISTIC RELIABILITY AND INTEGRITY ASSESSMENT OF LARGE DIAMETER STEEL COMPLIANT RISERS FOR ULTRA-DEEPWATER

III.3.5.1 Introduction

III.3.5.1.1 Background

Steel Catenary risers have proven to be effective solution for in-field flow lines, tiebacks and export systems in the US Gulf of Mexico. SCRs are being considered as cost effective solution for production in water depths up to and beyond 10,000 ft. The use of SCR at this water depth will require advancements in SCR engineering and analysis in order to ensure that the systems developed for such water depths are technically sound and safe, as well as economic. At the time of the study there were no existing SCRs in 10,000 ft water depth. The deepest existing SCRs were in 6000 ft water depth for the BP Thunder Horse project. The fatigue and extreme condition performance results from the two generic study cases (i.e. a truss spar and semi-submersible floating structures) indicated that SCR supported from appropriately designed spars and semi-submersibles is feasible in water depths up to and beyond 10,000 feet.

III.3.5.1.2 Technical Scope

The scope of this assessment study is summarized below:

- A review of worldwide SCR database
- Deterministic analysis of vessel mooring, riser hang off, riser fatigue and riser-soil interaction in 10,000m water depth.
- Development of a probabilistic reliability-based framework for SCR performance in ultra-deepwater.

III.3.5.1.3 Study Limitations

- The study was carried out based on generic field developments, for a future ultra-deepwater application a separate risk assessment may need to be carried out.

The risks considered in the study were mainly structural risks. Other type of risks such as flow assurance risks were not considered in the study.

III.3.5.2 Project Conclusions

III.3.5.2.1 Key Conclusions and Results

In summary, the results are:

- Fatigue and extreme performance results from the two generic study cases (i.e. a truss spar and semi-submersible floating structures) showed that ultra-deepwater production using SCR supported from appropriately designed spars and semi-submersibles is feasible.
- The conventional analysis tools used for SCR design were found to be safe and conservative when compared with the latest available tools for design.
- Application of SCR for ultra-deepwater applications was assessed using similar analysis methods for conventional SCRs. The use of SCR for ultra-deepwater application was considered to be safe although there is a risk that for certain cases, the use of conventional analysis method may indicate the use of SCRs is non-feasible or less economic.

- Probabilistic fatigue reliability estimates produced results that complemented the predictions from the deterministic analysis approach suggesting that the hang-off region is consistently the most critical in terms of fatigue

III.3.5.2.2 OSER Goals

SCRs are proven solutions for oil and gas production in deepwater. The reliability of the technology in ultra-deepwater application (~ 10,000m) is not well understood. The study successfully analyzed the behavior of SCR in ultra-deepwater for two fields developed with a spar and a semisubmersible. The study was able to demonstrate the feasibility of SCRs for ultra-deepwater applications which is consistent with one of the goals of the Operational Safety and Engineering Research Program (i.e. independent verification of emerging technologies).

III.3.5.2.3 Recommendations

The authors recommended:

- The use of full-coupled models for detailed engineering of deepwater SCRs to improve fatigue prediction accuracy.
- The continued use of conventional seabed models for detailed engineering of SCRs due to the conservation in prediction.
- For some ultra-deepwater applications, it is possible that the conventional design methods indicate the use of SCRs to be not feasible or un-economical. In such cases, the use of the more advanced analysis method may be appropriate.
- The continued use of the modal analysis method used for VIV calculations due to the conservation in prediction.

III.3.5.3 Current State of Knowledge

The current SCR design analysis includes static design used for riser sizing, followed by dynamic and fatigue analyses of the riser system. A simple Catenary solution is used to estimate the top angles and sag-bend bending and direct stresses of the riser. VIV analysis is carried out using current profiles to determine the fatigue life of the riser and VIV suppression device requirements. Extreme response is also computed for the riser system to determine tensions, stresses and upper-end rotations. SCR fatigue damage comprises contribution from FPS motion, direct wave loading, VIV excitation and installation loads.

In ultra-deepwater, the combined mass of the mooring lines, risers and umbilicals makes up a significant proportion of the system total mass. Hydrodynamic damping due to drag force on slender body is also significant. Conventional 'uncoupled analysis does not directly take account of contributions to inertial loads and damping from these components.

III.3.6 PROJECT NO. 490 – A COMPARATIVE RISK ANALYSIS OF COMPOSITE AND STEEL PRODUCTION RISERS

III.3.6.1 Introduction

III.3.6.1.1 Background

The polymer matrix composite materials, particularly glass-epoxy and carbon-epoxy composites, have drawn substantial attention from the offshore industry primarily due to their high specific strength as well as their property tailorability. The tailorability to specific strength and stiffness, thermal conductivity, resistance to corrosive fluids and damping properties is unavailable in any other material system. The weight reduction that can be attained by using a composite production riser (CPR) is substantial and will lead to significant cost savings.

Since the composite design has not been used in offshore applications, it is necessary to demonstrate that a composite riser meets the same requirements as the traditional steel risers at the onset. It is also essential that a comparative risk analysis be completed for steel and a composite production riser for a deepwater floating production system.

III.3.6.1.2 Technical Scope

The study examined the current state of technology, specifically the design and analysis considerations that are unique to offshore composite risers. The study was limited to production risers that are to be designed and manufactured as continuous fiber reinforced polymer matrix composites to be used in deepwater top tension risers. The scope of this study also included the examination of the relative risk of composite and steel production risers.

III.3.6.1.3 Study Limitations

At the time the report was issued, the principal barrier was the lack of databases and field trials that could be utilized with confidence for design life. In the ultra-deep water applications, the tendency to replace steel with composites from the mere perspective of weight savings was a dangerous direction which may lead to short term financial savings, yet could end up with a higher cost if the overall system concept was not properly employed. For the CPR analyzed in this study, only the riser joints and pup joints were composite joints and all other connector components (SJ, TJ etc) at the top and bottom of the riser were made from conventional steel. A study of complete replacement of all these steel components with composite components was beyond the scope of the study.

III.3.6.2 Project Conclusions

III.3.6.2.1 Key Conclusions and Results

The analysis showed that significantly less tension is required for the composite riser due to its lighter weight. The maximum bending moments at the TP were about the same, but were significantly smaller at the TSJ for the composite riser. The stress joint needed for the composite riser was considerably smaller and lighter than that required for the steel riser. Critical wall thicknesses in the TSJ for the composite were about one half those needed for the steel riser. The smaller TSJ and smaller tension requirements results in lower loads on the wellheads for the composite riser. The smaller tension requirements for the composite riser also allow a significantly smaller Tension Joint (TJ) to be used for the composite riser. The results of the risk analysis indicate that a composite production riser can be designed to be as safe as a steel production riser for deepwater applications in the Gulf of Mexico.

The composite components of the composite riser were designed to higher safety factors than those associated with the metal riser and should ensure the long-term integrity of the composite risers, it is recognized that situations may arise that will require assessing integrity of the joints after being in-service.

III.3.6.2.2 OSER Goals

It is one of the goals of the Minerals Management Service's Deepwater Operating Plan (DWOP) that new technology introduced in a deepwater development project be shown to be as safe as existing technology. Although the advantages of composites for riser materials have been debated over the years, the composite risers have not been used in the Gulf of Mexico to date. Consequently, developing a comparative risk analysis for steel and a composite production riser system would help to clarify the potential of this technology.

The Composite Production Riser study served as an independent verification of this emerging technology in terms of reliability and operational safety.

III.3.6.2.3 Recommendations

Further development of low-cost and reliable manufacturing techniques that can produce defect free composite components with simple and robust attachments is needed. Adequate experiments and analysis to establish databases commensurate with field trials that can be utilized with confidence for design life need to be developed. Reliable welding protocols at the metal liner-termination interface need to be qualified prior to installation.

A multi-scale test matrix needs to be developed with appropriate specimens at different scales to enable realistic data gathering and to experiment with different inspection techniques. The development of industry and regulatory acceptable design standards can greatly facilitate the approval process.

III.3.6.3 Current State of Knowledge

The results of comparative risk analysis of steel and composite production indicate that a composite production riser can be designed to be as safe as a steel production riser for deepwater applications in the Gulf of Mexico. At present, the principal barrier is still the lack of databases commensurate with field trials that can be utilized with confidence for design life. Transition from steel risers to composite riser depends on the development of field databases, robust terminations, standards, and flexibility in selecting optimum production/exploration platforms to take advantage of composites.

III.3.7 PROJECT NO. 487 – MAGNETIZATION EFFECTS ON HYDROGEN CRACKING FOR THICK WALLED PIPES

III.3.7.1 Introduction

III.3.7.1.1 Background

The integrity of pipelines, with high level of confidence and reliance, is ensured using intelligent inspection tools (intelligent pigs) and techniques by means of determination of localized Magnetic Flux Leakage (MFL). This technique is performed by magnetizing the steel pipe near the saturation flux density and then detecting a local flux leakage caused by anomalies in surface morphologies. Depending on the remnant magnetization left by MFL inspection tools, the steel may be more susceptible to hydrogen induced cracking. This research was aimed at studying the effect of magnetic induction generated by MFL inspection tools on the hydrogen content in commonly used pipeline steels and its influence on the hydrogen induced cracking susceptibility.

III.3.7.1.2 Technical Scope

The objective was to understand and describe the effect of high strength magnetic fields applied during frequent pigging to steel pipeline on the hydrogen-induced cracking susceptibility. This research project quantitatively measured the increased hydrogen activity in the thick walled, high strength steels due to the magnetization. The study was also to help establish if the augmented level of diffusible hydrogen was deleterious to the integrity of the pipes

III.3.7.1.3 Study Limitations

The experimental work carried out in this study employed a magnetic field at saturation level of approximately 2 Tesla (20,000 Gauss), similar to the saturation induction applied by MFL tools. The magnetization level left by the MFL tools after pigging for an indefinite period of time is much lower than the saturation level. The experimental work was carried out to study the effect of remnant magnetization after pigging on hydrogen absorption in unstressed and cold worked sections. The absorbed hydrogen concentration in steels is affected by steel deformation.

The effect of temperature on the susceptibility of pipeline steels to hydrogen damage under magnetization is unknown because the tests were run at room temperature.

The total absorbed hydrogen content in steels under magnetization increases considerably in pipeline steels; however, the cause of this is uncertain in terms of solubility or permeability of hydrogen. Hydrogen permeability or hydrogen diffusivity cells could be appropriately designed and setup in order to assess this phenomenon.

III.3.7.2 Project Conclusions

III.3.7.2.1 Key Conclusions and Results

- The results indicated that a strong, continuous magnetic induction produced by MFL pipeline pigging tools of approximately 2 Tesla (20,000 Gauss) causes an increase in the total absorbed hydrogen concentration in the tested high-strength pipeline steels of Grades X70 and X80 in a hydrogen environment
- This study proved that at a remnant magnetic induction of 1 Tesla (10,000 Gauss), the adsorbed hydrogen concentration in the tested high-strength pipeline steels increases by approximately sixty percent (60%). At saturation magnetization (i.e. during pigging), the concentration could be as high as six times
- Cold-working was shown to enhance the absorption of hydrogen up to 9.4 times more than non-cold-worked samples of X70 steel. The effect is less pronounced (3.7 times) in X80 samples.
- The reported results revealed that hydrogen damage or hydrogen induced cracking susceptibility of pipeline steels is negatively affected by magnetization at saturation levels. This suggests that the remnant magnetization left by magnetic flux leakage inspection tools might also significantly affect the susceptibility to this cracking mechanism; however, a conclusive effect is to date undetermined.

III.3.7.2.2 OSER Goals

This project has addressed the safety concerns relating to one of the widely used MPL inspection tools on the pipeline steels. It has experimentally demonstrated that magnetic induction generated by MPL inspection tools may increase the hydrogen content in pipeline steels and its influence on the hydrogen induced cracking susceptibility in pipeline steels. The finding of this research could have a significant impact on the reliability of the thick walled pipelines that have been subjected to extensive MPL inspection in the past. The aim of the study is inline with the OSER goals of investigating the techniques to best assess, retain or restore the integrity of aging offshore assets.

III.3.7.2.3 Recommendations

The pipeline magnetic flux leakage (MFL) tools leave a remnant magnetization value after inspection, which is held by the steel for a long period of time. The duration and decay of the remnant magnetization value in the pipeline after pigging needs to be explored. Also, the fact that whether the remnant magnetization affects the cracking mechanism in the same way as saturation magnetization needs further investigation.

The susceptibility of hydrogen damage of pipeline steels under magnetization conditions could be predicted scientifically. Predictive model based on magnetization level, mechanical properties and metallurgical features of steels, strain distribution or profile after deformation, as well as cathodic charging conditions should be developed.

III.3.7.3 Current State of Knowledge

Laboratory experiments in this study have demonstrated that magnetic induction accelerates the hydrogen damage phenomenon. The effect of magnetization in terms of hydrogen content is much higher in steel of Grade X52 than of Grade X70 and X80. Under a strong magnetic induction condition, the susceptibility of low strength steels to hydrogen damage seems to be worse. The authors of this study have extended the scope in Phase III and studied the effects of magnetic fields in corrosion, pitting and cracking behavior and published a report on 4/14/10. Pipelines are designed conservatively and rely on inspection techniques such as magnetic flux leakage (MFL) pigging tools. The findings of this project could impact current standard industry practices and warrant further understanding and considerations on inspection technologies.

III.4 CORROSION

III.4.1 PROJECT NO. 496 – DESIGN OF CATHODIC PROTECTION SYSTEMS FOR DEEPWATER COMPLIANT PRODUCTION RISERS

III.4.1.1 Introduction

III.4.1.1.1 Background

At the launch of the JIP, there was no widely-accepted systematic approach for Cathodic Protection (CP) systems for deepwater risers.

Increase in the use of Steel Catenary Risers (SCR's), especially in deep and ultra deep waters, now have riser lengths in excess of industry accepted spacing for sacrificial bracelet anodes. Although it is not an unsolvable problem, the mathematical calculations and methodologies involved are complex and not readily understood. Thus general guidance on how to address these issues is needed by the offshore energy industry.

III.4.1.1.2 Technical Scope

The scope of this study was to identify the general concepts and methodology used for CP attenuation modeling of SCR's which are electrically continuous (shorted) and electrically isolated from the host facility.

III.4.1.1.3 Study Limitations

- It is a fundamental assumption in this study that all riser systems will be structurally designed in accordance with a recognized industry code of practice for riser design.
- The mathematical derivation of CP attenuation is essentially an in-depth analysis of Ohm's law and Kirchhoff's law as they are applied to the electrical circuit of the SCR/pipeline and anode source(s). Simply put, the sum of all the voltage drops in the circuit cannot exceed the voltage difference between the anode and the minimum allowable CP potential of the SCR (driving voltage).
- The study assumes that SCR and pipeline are of the same pipe type, i.e. outside diameter, wall thickness, coating type and coating thickness. In practice this is seldom the case. The methodology as presented is essentially the same, but

additional calculations based upon the presented calculations will need to be added to satisfy these boundary conditions.

- Failure modes of this approach would be a calculated CP potential of the SCR to be more positive than the minimum allowable CP potential. Current regulations and standards require the carbon steel to be catholically protected to a potential more negative than -0.800 $V_{Ag/AgCl}$ throughout the life of the structure.

III.4.1.2 Project Conclusions

III.4.1.2.1 Key Conclusions and Results

In summary, the results are:

- General CP methodology and calculations were presented for a basic SCR / Pipeline configuration for both electrically continuous and isolated conditions with the host structure.
- CP potential attenuation can be modeled for verification that all portions of the SCR can be adequately protected by anodes located at the end points throughout its design life.
- A simple software package was developed for calculating the CP attenuation for the two basic configurations riser configuration.

III.4.1.2.2 OSER Goals

This document supports the CP design/evaluation portion of the risk-based integrity management of SCRs. The document shows that potential profile (attenuation) modeling of an SCR can be performed to show that all CP potentials for the SCR will meet or exceed the minimum requirements for cathodic protection as established by recognized industry standards and government regulations.

The aim of the study is inline with the OSER goals of investigating the techniques to best assess, retain or restore the integrity of aging offshore assets

III.4.1.2.3 Recommendations

Although the authors do not present any recommendations in the report, they did identify and present solutions for the following:

- Calculating the CP potentials along a SCR from the host structure to the pipeline tie-in.
- Anode resistance modeling and calculations for multiple anode arrays (clusters)
- Identifying that even if SCR's are intentionally electrically isolated, it is possible for the isolating fittings to fail.
- Cathodic protection of SCR's utilizing anodes located at either or both ends is possible.

III.4.1.3 Current State of Knowledge

Since the publication of this report in 2005, ANSI & NACE has adopted a modified version of the ISO 15589-2 document, which includes many of the findings and methodologies of this report in 2007 [6].

III.5 REFERENCES

6. ANSI/NACE SP0607-2007. "ISO 15589-2: 2004, (Modified) Petroleum and natural gas industries – Cathodic protection of pipeline transportation systems - Part 2: Offshore pipelines. 1st Edition, November 5, 2