ANNEX X
Arctic Research Projects

CONTENTS

X.1 SUMMARY OF PROJECTS

This section of the report provides a summary of some significant recent research initiatives and challenges particular to the arctic environment, namely:

- Ice formation on structures (harmful effects of ice);
- Arctic pipelines (effects of ice and design constraints on pipelines);
- Exploration and production structures (potential of developing arctic structures for exploration and production).

X.1.1 ICE FORMATION ON STRUCTURES

Ice formation poses a significant challenge to the safe design and retention of structural integrity in the arctic offshore environment. Superstructure sea spray icing and atmospheric icing from various sources reduce the safety of offshore platforms and supply boat operations. These sources originate from snow, freezing rain, freezing drizzle, rime, sleet, and frost. As such, MMS TA&R Program has funded research into the understanding and mitigation of ice formation on structures, as represented by TA&R Projects No. 596 and 597 below. Detailed summaries of these projects are provided in a later section of this Annex.

Figure X.1: Sea spray icing on the Ocean Bounty (1979-1980 Winter)

X.1.1.1 Project No. 596 – Sea Spray Icing of Drilling and Production Platforms

The need for the research was to determine quantitatively the ice spraying due to wave and current loadings in the arctic conditions on offshore structures, such as rigs and drilling platforms. This need led to various analytical models, which were deemed capable to predict the ice spraying in terms of physical variables, such as ice cover, droplet diameter, wind speed, liquid water content and the velocity of the droplets to form ice on structures.

X.1.1.2 Project No. 597 - Assessment of Superstructure Ice Protection as Applied to Offshore Oil Operations Safety: Problems, Hazards, Needs and Potential Transfer Technologies

Prior to this study, a variety of deicing and anti-icing technologies had been tested on offshore platforms and boats with little overall success. To address this technology gap, fifteen new technologies and modern versions of old technologies now used successfully in aviation, the electric power industry, and on transportation systems were reviewed for application on offshore platforms for deicing. Overall, the presented technologies were deemed promising and may be beneficially employed as new marine ice protection systems, although specific application to the offshore environment should be assessed.

X.1.2 ARCTIC PIPELINES

The arctic environment also poses unique challenges for pipelines, particularly with regards to detailed data collection and assessment of ice gouging, strudel scouring, and upheaval buckling. TA&R Projects No. 577 and 601 represent endeavors to expand capabilities in this area. Detailed summaries of these projects are provided in a later section of this Annex.

X.1.2.1 Project No. 577 - Design Options for Offshore Pipelines in the US Beaufort and Chukchi Seas

The design of arctic pipelines and protection requirements for mechanical integrity oftentimes are driven by hazards such as ice gouging, strudel scour and upheaval buckling. The objective of the study was to assess the design options for pipelines and provide a risk analysis for strudel scour, upheaval buckling and ice gouging specifically in the Beaufort and Chukchi Seas.

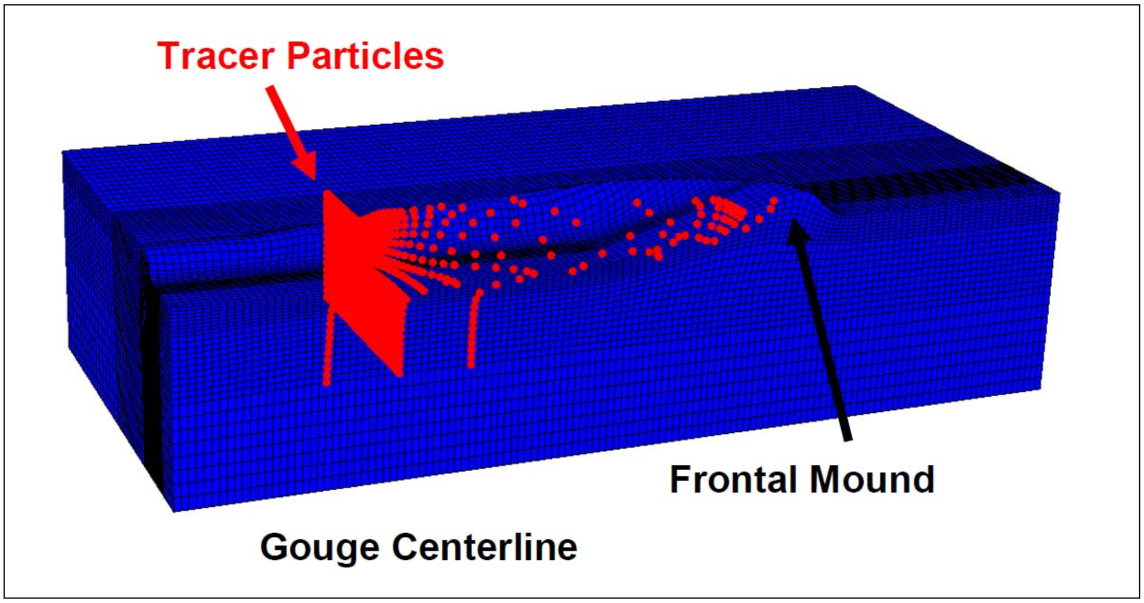

Figure X.2: Finite Element Ice Gouging Model

X.1.2.2 Project No. 601 - Seabed Scour and Buried-Pipeline Deformation due to Ice Ridges

The objective for this research was to model the ice gouging phenomena quantitatively. A simplified, yet computationally advanced approach using computational fluid dynamics (CFD) is adopted to predict the ice gouging deformations in an assumed array of pipes. The ice gouging phenomena is an important potential hazard to the pipelines in arctic regions, and therefore it is important to design the proper yet cost effective burial depths for the arctic pipelines, to prevent against excessive deformations. These excess deformations can result in permanent damage to the pipelines, resulting in large financial and environmental hazards. Therefore, this project addresses the quantitative modeling of ice gouging from view point of arctic pipeline designs.

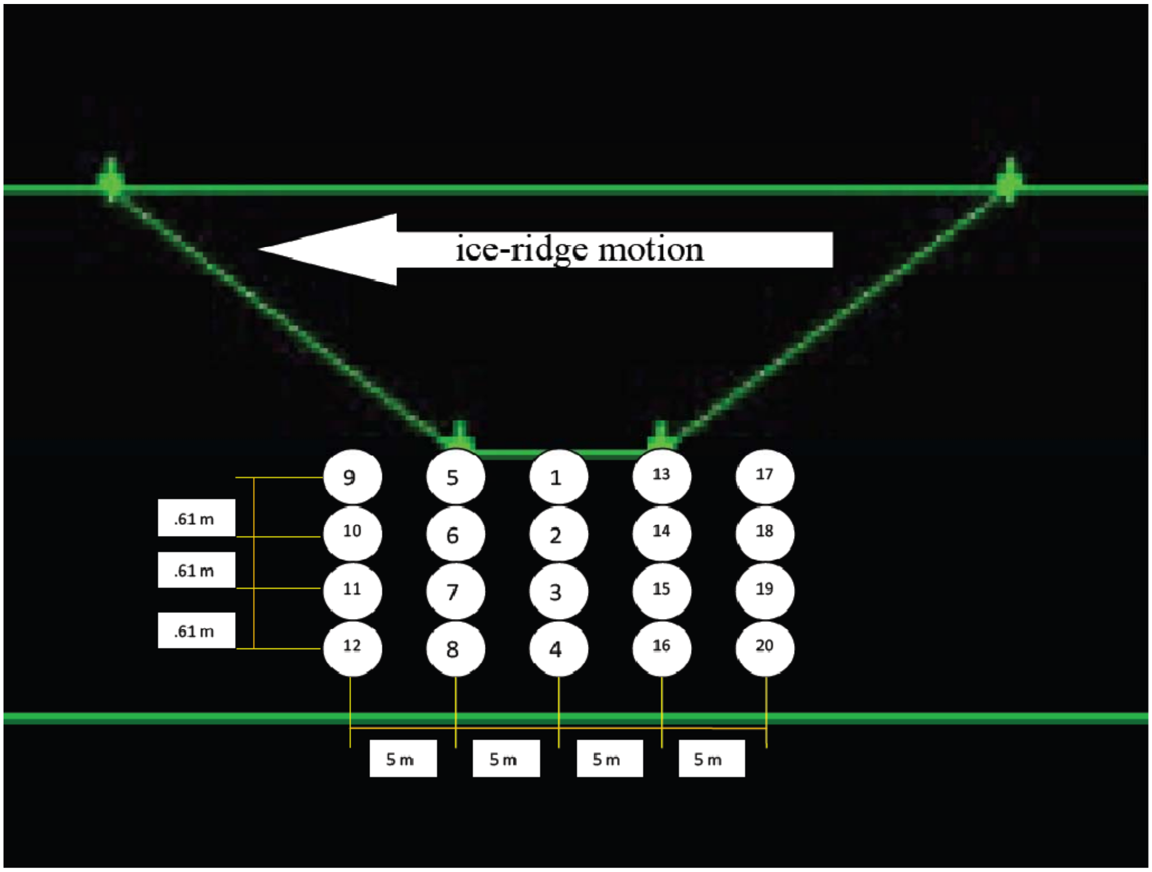

Figure X.3: Array of cylindrical surfaces ("pipelines") on which soil pressure and shear distributions are extracted from the FLUENT steady state computations

X.1.3 EXPLORATION AND PRODUCTION PLATFORMS

Three (3) TA&R projects have been conducted into existing and future exploration and production platforms in the arctic regions, with their associated noise problems and its control. These projects are TA&R Projects No. 468, 538, and 584. Detailed summaries of these projects are provided in a later section of this Annex.

X.1.3.1 Project No.468- Ice Island Study

The use of man-made ice islands as exploration drilling structures in the Canadian Arctic Islands and Beaufort Sea was reviewed, with an eye to overall safety, efficiency and cost of ice island construction and operation. The study reviewed available data from research and operational activities; defined state-of-practice based on methodologies current to the time of the study; and identified critical areas in which advances could be made through additional focused research. The review of the use of experimental and operational ice islands, primarily in the Beaufort Sea, demonstrated the advantages of spray ice production over other methods of construction, such as gravel islands or flooded ice production.

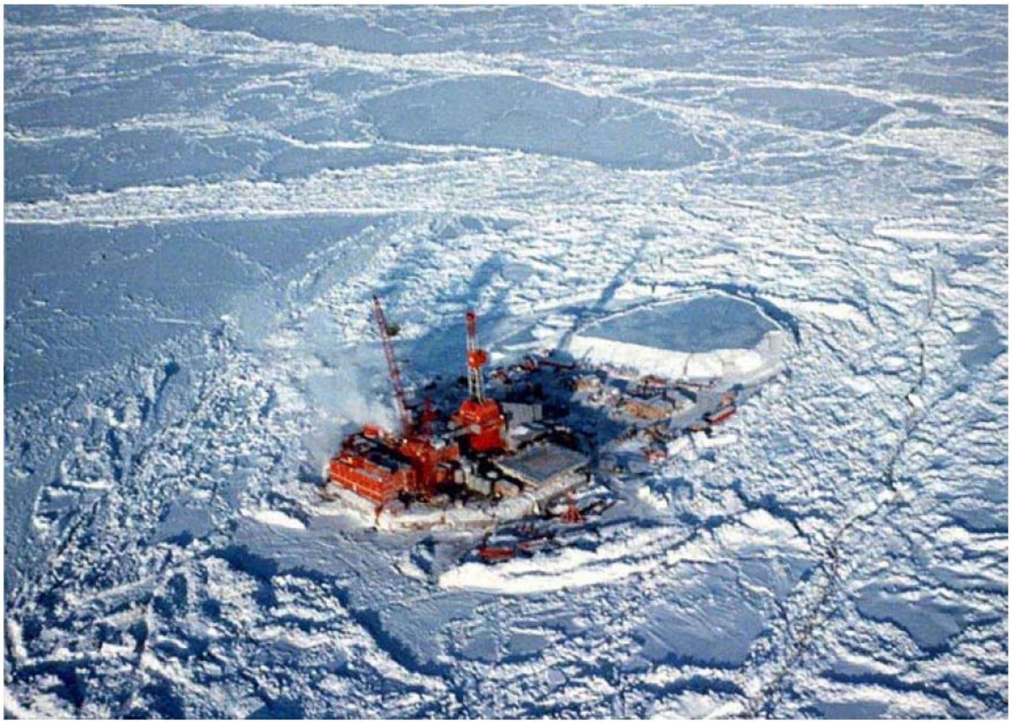

Figure X.4: Tarsiut Relief Spray Island

X.1.3.2 Project No. 538- Controlling Underwater Noise from Offshore Gravel Islands during Production Activities

The purpose of this study was to develop noise control treatments that can reduce the underwater radiated noise from future oil and gas production operations on gravel islands as compared with current designs.

X.1.3.3 Project No. 584- Exploration and Production Options for Cold Regions of the US Outer Continental Shelf

The significance of oil and gas prospects in the arctic is expected to lead an inevitable need for developing technologies specific to this new frontier. An exhaustive assessment of oil and gas technologies that may be applied to cold regions of the United States Outer Continental Shelf (OCS) was conducted, emphasizing the advances in harsh environment offshore exploration and production technology that have made it economically and technically feasible for projects to proceed in ice-covered waters.

Figure X.5: Arctic Caisson Drilling Structures

X.2 ICE FORMATION ON STRUCTURES

X.2.1 PROJECT NO. 596 – SEA SPRAY ICING OF DRILLING AND PRODUCTION PLATFORMS

X.2.1.1 Introduction

X.2.1.1.1 Background

The need for the research was to determine quantitatively the ice spraying due to wave and current loadings in the arctic conditions on offshore structures, such as rigs and drilling platforms. This need led to various analytical models, which are presented in the research project. The models are used to predict the ice spraying. The models are also used to compare with data available on two platforms from late 70's and early 80's.

X.2.1.1.2 Technical Scope

The project presents an analytical model of ice accretion through wind and wave loadings on the offshore platforms. The model is applied to the semi-submersible drilling rig, called Ocean Bounty, in the winter of 1979-80, and the Sedco 708 in January 1983. The model results compare closely with the test data on these platforms.

X.2.1.1.3 Study Limitations

The research addresses an analytical model, which needs further verification against more test data. So more test data on fixed platforms in cold regions is required. Furthermore, the phenomena should be modeled by more advanced, nonlinear tools, such as finite element method (FEM), so as to have more checking benchmarks for the analytical model.

X.2.1.2 Project Conclusions

X.2.1.2.1 Key Conclusions and Results

In summary, the conclusions were:

- A physically sound quantitative model of the ice accretion phenomena on fixed offshore structures was developed.
- The model was deemed capable to predict the ice spraying in terms of physical variables, such as ice cover, droplet diameter, wind speed, liquid water content and the velocity of the droplets to form ice on structures.

X.2.1.2.2 OSER Goals

The research project addresses the second goal of OSER, for assessing the integrity of the platforms, since ice accretion can cause large ice forces, which can cause a platform to lose its buoyancy.

X.2.1.2.3 Recommendations

To obtain more test data for the Alaskan cold regions on the platforms, in order to assess and improve the model.

X.2.1.3 Current State of Knowledge

Currently there are no rigorous modeling techniques (either analytical or computational) that address the ice accretion on offshore platforms and structures. This research project can be regarded as a starting step in this direction, which can lead to highly useful and important techniques for assessing the ice loads and their remediation.

X.2.2 PROJECT NO. 597 - ASSESSMENT OF SUPERSTRUCTURE ICE PROTECTION AS APPLIED TO OFFSHORE OIL OPERATIONS SAFETY: PROBLEMS, HAZARDS, NEEDS AND POTENTIAL TRANSFER TECHNOLOGIES BACKGROUND

X.2.2.1 Introduction

X.2.2.1.1 Background

Superstructure sea spray icing and atmospheric icing from various sources reduce the safety of offshore platforms and supply boat operations. These sources originate from snow, freezing rain, freezing drizzle, rime, sleet, and frost. Platforms operating in cold regions are protected primarily by designs that reduce ice accretion, coupled with the selective use of heat. A variety of deicing and anti-icing technologies had been tested on offshore platforms and boats, but with little overall success. This research puts forward the proposal to use new technologies and modern versions of old technologies, now used successfully in aviation, the electric power industry, and on transportation systems in general, on offshore platforms for performing the deicing. The presented technologies are the population from which new marine ice protection systems may be selected.

X.2.2.1.2 Technical Scope

The research project delineates various classes of de-icing and anti-icing technologies and proposes investigation for their use on cold regions fixed offshore platforms. The research project identifies chemical and numerous other modern day technologies that had been used successfully in other industries, and proposes their use for offshore cold regions.

X.2.2.1.3 Study Limitations

The key limitation is that the use of various presented technologies (total of fifteen) was not demonstrated to be applied on fixed marine offshore platforms. The idea of using de-icing techniques from other industries was strongly advocated, with each method having their own advantages and limitations. However, there still is a need to see the applicability if these methods in, say, an offshore drilling rig or platform to deice these structures, to change from hazard to an inconvenience.

X.2.2.2 Project Conclusions

X.2.2.2.1 Key Conclusions and Results

A number of transportation and aviation de-icing technologies were presented, with industrial contacts. In addition, advantages and limitations of each of the method were highlighted. The research study should provide an optimistic practical step towards usage of technology for de-icing the offshore fixed platforms.

In summary, the results were:

- Engineering information available from manufacturers, developers, vendors, patents, literature and experience was used to obtain an assessment of the capabilities of ice protection technologies that can be used in the marine environment. In addition, technology readiness level for each of the technology as can be applied to the marine environment was described.

- Ice protection technologies from other disciplines experiencing icing, especially from the highway, aviation, and electric power transmission industries, were summarized and matched to specific marine needs.

X.2.2.2.2 OSER Goals

The project aligns with the second goal of OSER, in terms of assessment of fifteen classes of de-icing and ice removal technologies, to retain or restore the integrity of fixed marine platforms, in order to reduce the hazard and make the offshore operations more accessible in cold regions.

X.2.2.2.3 Recommendations

Apply the recommended technologies to simulated or actual arctic structures and assess the results. In addition, perform more research on refining the technologies.

X.2.2.3 Current State of Knowledge

The research outlined current emerging and renovated technologies for ice cooling in various industries, such as Chemicals, Coatings, and Electrical Techniques. No significant development was noted in these technologies since the study was conducted.

X.3 ARCTIC PIPELINES

X.3.1 PROJECT NO. 577 – DESIGN OPTIONS FOR OFFSHORE PIPELINES IN THE US BEAUFORT AND CHUKCHI SEAS

X.3.1.1 Introduction

X.3.1.1.1 Background

The design of arctic pipelines and protection requirements for mechanical integrity oftentimes are driven by hazards such as ice gouging, strudel scour and upheaval buckling. The objective of the study was to assess the design options for pipelines and provide a risk analysis for strudel scour, upheaval buckling and ice gouging specifically in the Beaufort and Chukchi Seas.

X.3.1.1.2 Technical Scope

The study provided a detailed review of design issues relating to protecting Arctic offshore pipelines from ice gouging, strudel scour and upheaval buckling. The study presented interpretation of seabed survey data, analysis methods for pipeline response and demonstration of design methodologies for selection of the pipeline burial design depth. The study focused on the US Beaufort and Chukchi Seas.

Ice gouge data from surveys performed in the Beaufort and Chukchi Seas by the US Geological Survey in the 1970s and 1980s, and surveys related to the Northstar and Liberty Field developments was reviewed and processed to provide a statistical representation of gouge geometry (depth and width) and crossing frequency. Consideration was given to the survey limitations in terms of gouge cut-off depth, differentiation of single and multiplet gouges, potential sediment infill rates, dating of gouges through repetitive mapping and extrapolation of design parameters beyond data availability. Probability of exceedance curves for gouge depth, width and crossing density or frequency were developed based on the available data for input into a probabilistic design process.

Strudel scour seabed survey data related to the Northstar and Liberty Field developments were reviewed to develop statistical representation of strudel scour depth, diameter and formation density. Exceedance curves were developed in a similar manner to ice gouging. Issues relating to greater uncertainty due to a less comprehensive data source were noted.

Methods of analysis for the assessment of pipeline behavior as a result of ice gouging or strudel scour action were presented. Discussion of available models for calculating soil displacements, pipeline structural behavior and definition of failure criteria was presented as a framework for a probabilistic approach to pipeline design. Assessment of upheaval buckling potential, in combination with ice gouging was also discussed.

Probabilistic assessments of pipeline burial depth requirements for protection from ice gouging and strudel scour were presented based on an example pipeline route and design parameters. The examples demonstrated an approach that uses the survey data interpretation and analytical methods discussed through the report. The examples suggested that ice gouging presented an important design challenge, with significant burial depths being required. Strudel scour was found less onerous based on interpretation of data available to the study.

A brief discussion of construction, maintenance and repair of pipelines in Arctic conditions was provided. This aspect of project development was considered particularly important to provide the required confidence that systems can be designed, built and operated safely.

X.3.1.1.3 Study Limitations

A detailed assessment of the construction, maintenance and repair of pipelines in Arctic conditions was not provided.

X.3.1.2 Project Conclusions

X.3.1.2.1 Key Conclusions and Results

Conclusions and recommendations of the study can be summarized in the following:

Ice Gouging

- Ice gouging is an important condition that must be considered as part of the offshore design process. Predicted burial depth requirements using currently available data and analysis methods can be significant and can control design conditions.

- There is a need for significantly increased regional coverage of repetitive mapping of the US Beaufort and Chukchi Seas to provide improved parameters of ice gouge geometry and crossing rates. Experience in the Canadian Beaufort Sea, where annual government funded surveys had taken place over the 10 years preceding the study or more, suggests that many years of data are needed to adequately provide statistical parameters for design. Consideration of infilling and erosion of gouges between formation and surveying must be considered.
- A consistent approach to reporting of gouge parameters, such as the differentiation of single and multiplet gouges and disturbed width should be developed to remove uncertainty in its interpretation.
- The statistical interpretation of gouge geometry to account for long return periods currently requires significant extrapolation beyond the available data. A greater quantity of survey data would reduce the need to extrapolate, but recognition of physical boundaries of the gouging process is required to establish gouge criteria that results in safe and economical designs.
- Methodologies available at the time of the study for the analysis of pipeline response to ice gouging predict significant burial depth requirements for the conditions experienced in the Beaufort and Chukchi Seas. Efforts are ongoing by a number of researchers to improve the level of understanding of ice gouging processes and develop the models that feed into burial depth design requirements. This is expected to improve the efficiency and lead to reduced cost for future projects in this region.

Strudel Scour

- The risk of strudel scour to pipelines does not seem to be significant based on the data and conditions reviewed by the study.
- There is a small amount of data available for defining the risk to a pipeline, although efforts are ongoing to define areas where this process is expected to occur. Additional data will be required to define strudel scour geometry and formation density.
- Simple analytical methods can be developed to allow pipeline behavior to be predicted when spanning a strudel scour. This is expected to be sufficient for preliminary design and for determining if this condition has a large impact on burial depth. More detailed modeling may be warranted where the risk of strudel scour may dominate the design condition.
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Pipeline Buckling

- Upheaval and lateral pipeline buckling are considerations for all pipelines. Accepted routine design methods were developed to predict the onset of this behavior. Arctic conditions have the potential to increase the severity of buckling due to increased temperature differentials between installation and operation.
- The interaction of buckling behavior with ice gouging or strudel scour should be considered, and existing design methods may be modified to allow such checks to be performed.

X.3.1.2.2 OSER Goals

This study attempted to verify the adequacy of Arctic pipeline design methodologies and industry practices, available at the time of the study, regarding strudel and ice scour and lateral and upheaval buckling. The study also aimed at assessing the risk these hazards constitute to pipelines laid in Arctic oil and gas fields, based on field data compiled as part of the study. Indeed, the study verified the need for enhancement of the level of knowledge and development of design tools, to be able to cover the gaps in the knowledge and technology.

X.3.1.2.3 Recommendations

The recommendations from the research project related mostly to the ice gouging phenomena, and they are summarized as follows:

- There is a need for significantly increased regional coverage of repetitive mapping of the US Beaufort and Chukchi Seas to provide improved parameters of ice gouge geometry and crossing rates. Experience in the Canadian Beaufort Sea, where annual government funded surveys had taken place over the 10 years preceding the study or more, suggests that many years of data are needed to adequately provide statistical parameters for design. Consideration of infilling and erosion of gouges between formation and surveying must be considered.
- A consistent approach to reporting of gouge parameters, such as the differentiation of single and multiplet gouges and disturbed width should be developed to remove uncertainty in its interpretation.

- The statistical interpretation of gouge geometry to account for long return periods currently requires significant extrapolation beyond the available data. A greater quantity of survey data would reduce the need to extrapolate, but recognition of physical boundaries of the gouging process is required to establish gouge criteria that results in safe and economical designs.

Related to pipeline buckling, the recommendations are as follows:

- Upheaval and lateral pipeline buckling are considerations for all pipelines. Accepted routine design methods were developed to predict the onset of this behavior. Arctic conditions have the potential to increase the severity of buckling due to increased temperature differentials between installation and operation.
- The interaction of buckling behavior with ice gouging or strudel scour should be considered, and existing design methods may be modified to allow such checks to be performed.

X.3.1.3 Current State of Knowledge

Currently, there are not standard design recommendations for designing against ice gouging and strudel scour. There is more need to develop the analytical design guidelines, coupled with advanced modeling, to help engineers dealing with these arctic pipeline challenges. Finite element analysis (FE) techniques have been used for modeling pipeline buckling for many years. Advanced techniques of the FE, such as Arbitrary Lagrangian-Eulerian (ALE) and Coupled Eulerian-Lagrangian (CEL) have successfully been used for modeling ice gouging.

X.3.2 PROJECT NO. 601 – SEABED SCOUR AND BURIED-PIPELINE DEFORMATION DUE TO ICE RIDGES

X.3.2.1 Introduction

X.3.2.1.1 Background

The objective of this research was to model the ice gouging phenomena quantitatively. A simplified, yet computationally advanced approach using computational fluid dynamics (CFD) is adopted to predict the ice gouging deformations in an assumed array of pipes. The ice gouging phenomena is an important potential hazard to the pipelines in arctic regions, and therefore it is important to design the proper yet cost effective burial depths for the arctic pipelines, to prevent against excessive deformations. These excess deformations can result in permanent damage to the pipelines, resulting in large financial and environmental hazards. Therefore, this project addresses the quantitative modeling of ice gouging from view point of arctic pipeline designs.

X.3.2.1.2 Technical Scope

The technical scope of this project is to analyze an array of pipe cross sections buried under an elastic-plastic soil (assumed model for the soil) and gain important knowledge about the stresses and deformations in the pipelines, as well as the associated bending moments. The project does not model the pipe-soil interaction; the pipes are modeled as vacant circular sections at specified arrays in the soil. The ice ridge is modeled as a rigid body, impacting the soil at various velocities. The soil is modeled using the CFD commercial software, FLUENT, with specified material properties which are strain rate dependent.

X.3.2.1.3 Study Limitations

The pipe soil interaction is not modeled. Moreover, one type of material model is assumed. Experimental verification needs to be conducted.

X.3.2.2 Project Conclusions

X.3.2.2.1 Key Conclusions and Results

In summary, the results are:

- The model provides computationally simple model using the CFD, for modeling the challenging ice gouging phenomena.
- The model is used to obtain some important preliminary results for suitable pipe wall thickness and burial depth for pipelines against the ice gouging, under various keel velocities.

X.3.2.2.2 OSER Goals

The project addresses the second goal of OSER, by modeling the detrimental ice gouging phenomena, which will provide quantitative determination of safe burial depth against the ice gouge, and to prevent excessive pipe deformations.

X.3.2.3 Recommendations

To model in more detail the seabed-pipe interaction. Also conduct some model tests and compare the results with the models.

X.3.2.4 Current State of Knowledge

The study used computational fluid dynamics (CFD) to estimate the soil response and associated deformation in the pipe. Since CFD is relevant only to viscous materials, the study was confined to using viscous constitutive models of soil. However, new finite element (FE) techniques such as Arbitrary Lagrangian-Eulerian (ALE) and Coupled Eulerian-Lagrangian (CEL) have successfully been used for modeling ice gouging. These techniques are not computationally very efficient but have wider ranges of soil material models (including viscous models) and, consequently, provide more accurate representation of the response of the soil and pipe. Further, sine the study did not report the simulation run times, it was not clear which technique (CFD or FE) are more computationally efficient.

X.4 EXPLORATION AND PRODUCTION STRUCTURES

X.4.1 PROJECT NO. 468 – ICE ISLAND STUDY

X.4.1.1 Introduction

X.4.1.1.1 Background

Spray ice production technology has been developed over more than 30 years to meet the requirements of the industry, particularly prior to 1986 when exploration activity was high in the Beaufort Sea. To increase safety and efficiency and reduce cost of ice island construction and operation, the study is aimed to review available data from research and operational activities with respect to ice island design, to construction and maintenance; define state-of-practice based on methodologies current to the time of the study; and to identify critical areas in which advances could be made through additional focused research.

X.4.1.1.2 Technical Scope

This report summarized the issues related to the use of man-made ice islands as exploration drilling structures in the Canadian Arctic Islands and Beaufort Sea. The historical development of ice island technology was reviewed with respect to design, construction and maintenance issues relating to the use of both floating and grounded islands. The study addressed the opinion of a number of experts who, between them, had had direct involvement in all ice islands constructed in North America.

The range of pump and nozzle configurations used in practice was reviewed to establish the parameters required to produce spray ice in an efficient manner. Potential improvements to ice island technology were also investigated, such as their use in deeper water and potential for extending the available drilling season.

Constraints to operational efficiency due to wind and temperature variations were considered, and the use of innovative methods to further improve efficiencies in design and construction was presented. Methods included the use of alternative ice production techniques when weather conditions are unsuitable for spray ice production, methods of reducing ice loads through suppressing natural ice thickness, and the use of structures to form rubble piles to reduce the required spray ice volume.

A centrifuge model test was performed to demonstrate the potential applicability of this technique to investigate ice island performance. The test simulated ice loading on an island to produce sliding failure, and compared the results with the calculated capacity. The test results showed that under the conditions tested, the island deformed by failure of the ice core rather than by sliding along the seabed as predicted. The measured loads were greater than calculated, suggesting that current design methods could be optimized to further reduce cost. The use of centrifuge technology could be used to improve understanding and further development of design issues.

X.4.1.1.3 Study Limitations

Consideration of operational costs are usually important, and often an overriding concern, in determining the suitability of particular method of operation; however, detailed cost comparisons were not undertaken as part of the study.

X.4.1.2 Project Conclusions

X.4.1.2.1 Key Conclusions and Results

The review of the use of experimental and operational ice islands, primarily in the Beaufort Sea, demonstrated the advantages of spray ice production over other methods of construction, such as gravel islands or flooded ice production. Achievable cost savings were demonstrated to be significant as a result of using a natural material with no transportation costs, and high build up rates was shown to minimize construction time.

One critical design consideration for grounded ice islands was shown to be the determination of the ice loads applied to the island by the surrounding ice sheet. In that regard, significant difference in determining the ice crushing loads between the various codes of practice was shown. A number of potential failure mechanisms were investigated, which suggested that the limiting criteria might be either crushing of the ice sheet or edge failure at the interface between natural and spray ice, depending on site specific parameters.

The use of off-ice construction techniques, along with marine demobilization was shown to potentially achieve improvements with respect to their use in deeper water and potential for extending the available drilling season. Issues relating to ablation and edge erosion of ice islands at the end of the winter season had been investigated, including a brief evaluation of the requirements to allow an island to remain in place on a multi-year basis. The changes in temperature regime as a result of climate change over the past 30 years were reviewed. That suggested that although there was a large variability in conditions year-to-year, the trends did not suggest that the use of ice island construction in the Western Arctic would be impeded by this over at least a decade.

As to pump and nozzle configurations, efficiency generally was noted to improve when larger pumps were used, which allows individual particles to remain in flight for longer thereby undergoing greater heat transfer. Build up rates were also noted to maximize when large flow rate pumps were used.

The performance of a centrifuge model test in that study demonstrated the potential applicability of this technique to investigate ice island performance. The test simulated ice loading on an island to produce sliding failure, and compared the results with the calculated capacity. The test results showed that under the conditions tested, the island deformed by failure of the ice core rather than by sliding along the seabed as predicted. The measured loads were greater than calculated, suggesting that design methods at the time of the study could be optimized to further reduce cost. The study concluded that the centrifuge technology could be used to improve understanding and further development of design issues.

X.4.1.2.2 OSER Goals

This study attempted to verify the sufficiency and conservatism of design criteria used in constructing ice islands and to identify potential ways to increase these qualities. This has been sought through a review of the state-of-practice of construction and operation of ice islands and through carrying out centrifuge testing in an attempt to enhance the state of knowledge of the subject.

X.4.1.2.3 Recommendations

A number of potential areas suitable for further research were identified as a result of the review presented in this report. A list of issues was identified on the basis that improvements in these areas could lead to significant efficiencies in terms of reduced risk or reduced cost. The study suggested a consensus on the issues most likely to provide substantial improvements for the use of ice islands for offshore Arctic exploration could be developed through a forum with invited participants from industry, academia and government agencies. The main issues identified comprised the following:

- Ice sheet failure mechanics during impact with grounded structures
- Sliding resistance of grounded ice islands
- Ice island distortion during loading events
- Feasibility of construction of ice islands in deeper water environments
- Further study of the deterioration of ice island structures after the winter drilling season. Feasibility of ice island survival to allow multi-year operations
- Construction management techniques to allow improved feedback of construction related issues to the design
- Spray ice strength characteristics.

X.4.1.3 Current State of Knowledge

No significant industry recommendations have been issued regarding ice island design or construction subsequent to the study. However, currently, MMS TA&R Project No. 644, which aims to build a database of Ice Island and/or extreme ice feature motions, trajectories, and physical changes as they travel from the high arctic into the Beaufort Sea. Having this information will allow a better determination of the risks involved in putting a structure in the Beaufort Sea in different locations. Results from this project will also be compared with Ice Island and extreme ice feature information collected in the 1970s and 80s.

The study content reflects industry recommended practice by ISO-API RP 2N, 1995.

X.4.2 PROJECT NO. 538 – CONTROLLING UNDERWATER NOISE FROM OFFSHORE GRAVEL ISLANDS DURING PRODUCTION ACTIVITIES

X.4.2.1 Introduction

X.4.2.1.1 Background

The purpose of this study was to develop noise control treatments that can reduce the underwater radiated noise from future oil and gas production operations on gravel islands as compared with current designs.

X.4.2.1.2 Technical Scope

Northstar Island, operated by BP Exploration (Alaska) Inc. (BP), was used as the primary case study to uncover the pertinent mechanisms of underwater noise radiation from gravel islands. As part of the study, airborne noise and structural vibration data were collected on and around machinery items located on Northstar that are rated at 50 HP and higher. In addition, underwater noise data provided from external sources was measured at 400m North of Northstar Island during a time period shortly preceding the measurements at the island. The airborne noise, vibration, and underwater noise data were studied in an effort to identify primary sources of underwater radiated noise on Northstar and the dominant noise paths. This information was used to make general recommendations for the construction of future gravel islands, with the specific intention of reducing the underwater radiated noise generated during production activities relative to those measured at Northstar.

X.4.2.1.3 Study Limitations

The study did not include noise created by non-island sources such as boats that may be operating near the island during production activities. In addition, noise resulting from construction and drilling activities were specifically excluded from this study. It was noted that some of these sources had been shown to create higher underwater noise levels than those seen during gravel island "production only" activities.

X.4.2.2 Project Conclusions

X.4.2.2.1 Key Conclusions and Results

Analysis of available underwater noise data showed that virtually all detectable underwater noise caused by man-made sources occurs at frequencies below 250 Hz. Tones at 30 and 60 Hz were present in all analyzed data sets, indicating that they were a result of machinery that is virtually always running (in some form) such as power generation equipment. Many other tones were detectable in the various underwater noise measurements; however, all other tones were seemingly intermittent; i.e. they were seen in some underwater measurements and not in others. The sources of these tones were most likely caused by intermittent machinery operating on Northstar and/or machinery operating under varying loads. Other explanations related to sea conditions such as varying background levels and shallow water propagation effects may also be responsible for some of the variation seen in the underwater measurements.

In studying various potential noise paths from machinery items on Northstar to the surrounding water, it was found that two are dominant. The first was identified as the Primary Structure-borne Noise path, where noise is radiated into the water from the gravel itself due to vibrations created by machinery excitation. It was found that this is a viable path largely due to the fact that the gravel is compacted and acts as a solid, at least at low frequencies (i.e. below 250 Hz). Sources on Northstar identified by the study as being responsible for noise radiated through this path included the SOLAR Turbines, HP and LP Compressors, Water Injection Pump Skid, Air Compressors (2nd Level SPM), AHUs, and the Flare Blower, with possible minor contributions from the Oil Shipping Pumps and Water Booster Pumps. These sources were all rated at 800 HP and above, with the exception of the Flare Blower. Other sources located on the pad or not measured may also had created detectable underwater radiated noise.

The second dominant path was identified as the direct radiation from sea connected systems. It was noted that the actual influence of this path could not be determined from data collected in the study; however, that path was indicated to hold the potential for significant underwater noise and should be considered when designing future gravel islands. Other noise paths were found not to be feasible or to have secondary influences, at best.

The study concluded that including additional module structural stiffness at and near machinery foundations (relative to what is seen on Northstar) and resiliently mounting equipment with high-to-medium power ratings (i.e. above 500 HP) could reduce noise levels from 5-30 dB, depending on the exact design and configuration of the modules. The larger of these attenuation values is expected at frequencies near 60 Hz and above.

It is shown that a cofferdam can be designed to act as an acoustic muffler, providing significant transmission losses at low frequencies (on the order of 20-30 dB). Flexible connections and pulsation dampers can be used to further reduce noise from these sources; however, the performance of these treatments will depend on the specific usage and setup. In addition, all pumps should be located inside of modules; the use of submerged pumps on the perimeter of the gravel island should be avoided. While it is not possible to provide estimations of underwater noise reduction from these systems relative to Northstar, the treatment recommendations outlined in this report can be used to create systems with low underwater radiated noise.

Lastly, it was found that the noise radiated by the pipeline itself may cause detectable underwater noise levels at some distances. However, this finding is fairly uncertain as the transmission loss of sound through the sea floor is not known (the pipeline is located approximately 9 feet below the sea floor). It is recommended that noise transmission from this source/path be investigated further. As a precautionary measure, flex connections and/or pulsation dampers located at any pumps directly connected to the pipeline can be used to reduce noise from this source.

X.4.2.2.2 OSER Goals

This research addresses the long-term safety and environmental concerns due to level of noise and its control in offshore environments.

X.4.2.2.3 Recommendations

Although actual influence of direct radiation from sea connected systems could not be determined from data available to the authors, the study recommended such source of radiation be considered when designing future gravel islands.

The study also recommended that future designs gravel islands, source treatments for noise transmitted over the Primary Structure-borne Noise path include additional module structural stiffness at and near machinery foundations (relative to what is seen on Northstar) and resiliently mounting equipment with high-to-medium power ratings (i.e. above 50 HP). In addition, all equipment items should be properly mounted within a module. While tone detectability is based on the background noise levels at any given time, the authors indicated that implementation of these treatments should help to bring the underwater radiated noise levels closer to the background in the Beaufort Sea, and possibly below background in some cases.

Treatments for sea connected pumps were recommended to include the use of cofferdams for pump intake and outlet connections.

X.4.2.3 Current State of Knowledge

The current state of knowledge is limited to the measurements of noise on onshore structures. This is a step towards quantifying and mitigating the underwater noise from offshore production and operations.

X.4.3 PROJECT NO. 584 – EXPLORATION AND PRODUCTION OPTIONS FOR COLD REGIONS OF THE US OUTER CONTINENTAL SHELF

X.4.3.1 Introduction

X.4.3.1.1 Background

Lately, surveys has started to realize the significance of oil and gas prospects in the arctic and the inevitable need to develop technologies that would fit the new frontier. The objective of this study was to deliver an assessment of oil and gas technologies that may be applied to cold regions of the United States Outer Continental Shelf (OCS). Advances in harsh environment offshore exploration and production technology made it economically and technically feasible for projects to proceed in ice-covered waters.

X.4.3.1.2 Technical Scope

Project No. 584 assessed the state of offshore technology in arctic and sub-arctic regions at the time of the study. Results of that assessment were then used to provide insight and guidance into existing/future exploration and development technologies that might be applied on the US OCS, in particular those areas in the Beaufort, Chukchi and Bering Seas. The work covered exploration structures, bottom-founded and fixed production concepts, floating production concepts, terminals, pipelines and subsea facilities, and touches on other technologies that might be relevant to Alaskan OCS exploration and development.

The study draws on a review of current state-of-practice and state-of-the-art used in, or proposed for, arctic and sub-arctic offshore development areas. Assessments of exploration and production options are primarily based on technical feasibility. As appropriate, other aspects were also considered, including constructability, capital costs, environmental considerations, operations, maintenance and repair, abandonment and decommissioning.

Given the large geographic area encompassed by the Beaufort, Chukchi and Bering Seas, location scenarios were adopted to help focus the assessments. These locations were chosen based on current and historic activity and interest (including lease sales, drilling, studies, projects, etc.) and water depths (given the general differences in offshore facilities configuration with water depths). Overall applicability of the technology to the region of interest was also considered.

X.4.3.1.3 Study Limitations

The current study is an assessment, not a practical implementation of these technologies in Beaufort, Chukchi and Bering Seas.

X.4.3.2 Project Conclusions

X.4.3.2.1 Key Conclusions and Results

In summary, the technical feasibility of different options was concluded as follows:

Bottom-Founded Structures In multi-year ice areas of the Alaskan OCS, there are bottom-founded solutions (e.g., gravity base structure (GBS)) that would be considered safe and economical up to 200 to 250 ft water depths, depending on foundation properties.

There are no known bottom-founded platform design solutions for water depths greater than 330 ft that could be deemed workable or proven for multi-year ice areas. In the more southern areas, where multi-year ice is absent and only first-year consolidated ridge loadings are possible, bottom-founded solutions out to 500 ft water depths are potentially viable.

Jacket & Jack-up Structures Jacket platform was successfully used in sea ice. Earlier studies had suggested that jacket structures are suitable for areas of the Bering Sea. However, these studies did not consider the vibration responses associated with the dynamic ice loading. Jacket type structures could likely be made to work in light first-year ice and in water depths less than 200 ft. However, the jacket structure's potentially poor response to dynamic loading and the need for conductor system protection are significant design issues for application in the Bering Sea.

Design practices and understanding of jacket design at the time of the study made their application unsuitable for the Beaufort and Chukchi Seas. Developments in jack-up technology and the advancement of ice maintenance programs indicate that the operating range and season of jack-up exploration could potentially be extended in the Bering Sea.

Ice Islands Grounded ice islands had been used successfully as exploration drilling structures in near-shore areas of the US and Canadian Beaufort Sea. In practice, operational ice islands had been employed in water depths of up to 25 ft in the Beaufort Sea.

The use of operational ice islands might be achieved in water depths of up to approximately 30 ft. Incremental improvements in equipment capacity with higher productivity is liable to allow islands to be constructed into deeper water, e.g., 40 ft.

The use of ice islands in the near-shore Chukchi would likely be infeasible due to the unstable and unreliable landfast, or contiguous, ice zone. Ice islands would be generally infeasible for Norton Sound due to its warmer and shorter winter season. However, definite conclusions can only be reached through more detailed study.

Gravel Islands This simple technology has been successfully used in the Beaufort Sea for decades and continues to be viewed as a candidate structure for exploration and/or production in this area of the Alaskan OCS.

X.4.3.2.2 OSER Goals

The research reviews the use of existing technologies for potential application to arctic areas; in this way, it meets the first goal of OSER.

X.4.3.2.3 Recommendations

The authors recommended:

- Since no gravel island structure had been used in the Chukchi Sea, a more detailed assessment would be required to determine feasibility. Due consideration would need to be given to the fact that the near-shore Chukchi Sea ice environment may be more dynamic than the Beaufort Sea. In the near-shore Bering Sea, gravel islands may be subject to higher waves and larger wave loads, which would need to be taken into consideration during detailed assessment.
- It is generally agreed that environmental conditions (especially waves and ice conditions) are changing in the arctic. But no one knows definitively by how much, nor is there a compilation of current information (that the Study Team could find) that provides the information necessary to draw upon. It has been suggested by stakeholders that the MMS might consider a future study to compile, collect and/or

generate ice, metocean and meteorological information to be used by interested parties in screening studies.

- In carrying out this study, the Study Team identified additional information that would be "valuable to have" for future work. In addition, some technological areas were identified where advancements should be pursued, and these are also captured in this report.

X.4.3.3 Current State of Knowledge

The research utilizes the concepts and established drilling and platform designs from offshore energy industry to extend them to the arctic conditions. The current offshore engineering is fairly well established, with comprehensive design and installation solutions for fixed and floating platforms, pipelines and subsea structures. No additional developed has been noted since issuing the study.