OTC 12972

State of the Art of Removing Large Platforms Located in Deep Water

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This paper was prepared for presentation at the 2001 Offshore Technology Conference held in Houston, Texas, 30 April–3 May 2001.

Abstract

A study was conducted in November 2000 for the United States Department of Interior, Minerals Management Service (MMS) to identify and review state-of-the-art technologies for removing large offshore platforms located in deep water. Platforms emphasized on in this report were located in the Pacific Outer Continental Shelf Region (POCSR); comparisons were made to similar Gulf of Mexico platforms.

For this study, deepwater platforms were defined as those with jacket weights exceeding 10,000 short tons located in water depths exceeding 400 feet.

Three POCSR platforms (Hidalgo, Gail and Harmony) were selected to encompass the range of decommissioning conditions and to provide a thorough review of issues related to removing deepwater offshore structures. The water depths considered range from 430 feet to 1,198 feet.

Specific areas of technology reviewed included lifting, transportation, disposal, and explosive and non-explosive severing techniques. The three removal methods evaluated (using the best technology currently available) were Complete Removal, Partial Removal (reefing in place) and Remote Reefing (reefing off site).

Decommissioning cost estimates were prepared for the selected platforms and removal methods, including an evaluation of cost sensitivity (risk) issues and the cost of alternative technologies. Also assessed were environmental and human safety risks for current and evolving decommissioning technology. Specific recommendations were provided for industry and federal/state support for future developments.

Introduction

The overall goal of the MMS study was to determine and examine the issues relevant to decommissioning deepwater platforms and to quantify them in the context of economics, risk, and available technology. The following specific goals were achieved in this study:

1. Develop decommissioning plans for selected POCSR deepwater platforms using the best technology currently available.
2. Prepare decommissioning cost estimates for selected platforms and cases, including an evaluation of cost sensitivity (risk) issues and the cost of alternative technologies (i.e., explosive versus non-explosive severing methods).
3. Assess environmental and human safety risks for current and evolving decommissioning technology.
4. Provide a review of the state-of-the-art in decommissioning technology for: lifting, transportation, and disposal; explosive and non-explosive severing techniques.
5. Prepare specific recommendations for industry and federal/state support for future developments.

Scope of Work. The scope of work for the study consisted of selecting platforms to be evaluated; selecting and evaluating removal technology; developing decommissioning plans and cost estimates; analyzing safety and environmental issues; and reviewing and describing other removal technologies, their current development status, and prospects.

Project Issues

Offshore platform decommissioning is a challenge under any circumstances in terms of planning and executing the work in an environmentally sensitive, safe, and economical way. Regarding large deepwater platforms in the POCSR, this is particularly true. Among the issues that must be faced are:

Lack of Local Infrastructure. There are currently no derrick barges of significant capacity or other types of major marine construction equipment based on the West Coast, and none are likely to be in the foreseeable future. Additionally, there are currently no onshore facilities in California (or Mexico) capable of accepting jackets or topsides of these sizes, even in small pieces. The nearest such facility is in Portland, Oregon, eight to ten days sailing time away.

Challenging Marine Environment. The offshore California marine environment is very challenging to the type of large construction equipment and operations required for offshore platform decommissioning. Research has shown that conditions vary widely, with areas such as Point Arguello being subjected to rough seas, long period swells, and dense fog much of the year.

Limited Availability of Equipment. There are only four derrick barges in existence today, worldwide, with lifting capacities in excess of 5,000 short tons. These are generally committed to projects years in advance.

Environmental Regulation Constraints. California has a large number of regulations and a wide variety of federal, state, and local agencies enforce them. This has a direct impact on the application of decommissioning technologies and the resulting economics.

Depth Challenges. The industry has limited experience in applying decommissioning technologies at depths beyond 300 feet. New systems and procedures will likely be required for both explosive and non-explosive severing techniques. Safety will drive the use of divers and remotely-operated equipment.

Lack of Artificial Reef Legislation. Unlike the Gulf of Mexico oil and gas producing states, California currently has no enabling legislation for a rigs-to-reef program for offshore facilities. Such legislation is currently being discussed, but the timeline for its enactment is uncertain.

Methodology Selection

Figure 1 shows a Decommissioning Decision Tree that identifies all of the decommissioning methods that were considered for inclusion in this study. Topsides containing oil and gas processing equipment are assumed to be taken to shore and scrapped in all cases. Three methods for jacket disposal were selected to cover the range of costs and what are expected to be the most likely choices in the actual execution of POCSR platform decommissioning. These methods are equally applicable to the GOMR. The selected methods are: Complete Removal, Partial Removal, and Remote Reefing.

All of the assumed methodologies are consistent with current practices in the GOMR. However, it is important to note that contractors who operate large heavy lift vessels may not agree with the methods assumed (e.g., picking the jackets up and “hopping” them into shallower water so that all cuts are made in air). In general, the operators of the large heavy lift vessels have relatively little experience in platform decommissioning; what experience they have was primarily gained in North Sea operations.

Selected Platforms

The three platforms selected to cover the range of issues discussed in this report are Hidalgo, Gail, and Harmony. These platforms encompass the wide range of decommissioning options available and provide a thorough review of issues related to decommissioning deepwater offshore structures. The water depths for these platforms range from 430 feet to 1,198 feet. Table 1 presents an overview of the three platforms considered in this study.

Hidalgo. Hidalgo is an 8-main and 8-skirt pile ("8+8") drilling and production (“D&P”) platform installed in 1986 at a water depth of 430 feet. The platform is located 6 miles from shore in the Santa Maria Basin.

Jacket lift weight (including piles) and topsides weight (deck and modules) is estimated at 12,950 and 8,100 tons respectively. There are 10 conductors to remove and 2 originating pipelines to decommission.

Gail. Gail is an 8-main and 12-skirt pile ("8+12") D&P platform installed in 1987 at a water depth of 739 feet. The platform is located 10 miles from shore in the Santa Barbara Channel.

Jacket lift weight (including piles) and topsides weight (deck and modules) is estimated at 22,300 and 7,700 tons respectively. There are 22 conductors to remove and 3 originating pipelines to decommission.

Harmony. Harmony is an 8-main and 20-skirt pile ("8+20") D&P platform installed in 1989 at a water depth of 1,198 feet. The platform is located 6 miles from shore in the Santa Barbara Channel.

Jacket lift weight (including piles) and topsides weight (deck and modules) is estimated at 55,250 and 9,800 tons respectively. There are 51 conductors to remove and 2 originating pipelines to decommission. Additionally, there are 4 other pipelines connected to Harmony that originate at other platforms. The decision as to whether these pipelines will be abandoned or if they will tie-in to other pipelines at the time Harmony is decommissioned is up to the owner of the platform at which the pipeline originates.

Decommissioning Methodology

Standard cost components that should be accounted when developing offshore platform decommissioning estimates are as follows:

- Project Management & Engineering
- Heavy Lift Vessel mobilization
- Cargo Barge Mobilization
- Well P&A
- Platform Removal Preparation
- Pipeline Abandonment
- Conductor Removal
- Platform Removal
- Site Clearance and Verification
- Onshore Disposal

The MMS study provides detailed descriptions of each of the above phases of the decommissioning process. However, the removal alternatives considered – Complete Removal, Partial Removal, and Remote Reefing – vary only in the method the jacket is removed. Site clearance and onshore disposal methods also differ in that they are dependent on the removal alternative selected.

Cost Results Summary

Table 2 summarizes the decommissioning cost for each platform by removal method.

The removal method selected is a driving factor of each estimate. The Complete Removal scenario requires more HLV work, more cuts to be made to jacket legs and conductors, more cargo barges, and more travel time to tow all platform components to shore. Additional costs include site clearance/verification activities at each location the jacket is set down and cut and scrapping fees. The larger each platform is, the higher the Complete Removal cost. Partial Removal is the least expensive option. Cutting operations, HLV and cargo barge usage, and site clearance/verification time are minimized.

While the Remote Reefing option is less expensive than the Complete Removal scenario, HLV usage, and travel time make this removal method more expensive than Partial Removal. Additionally, the size of the platform directly correlates to its decommissioning cost. Deeper water depths often denote larger, more complex structures, which require larger heavy lift vessels and more conductor cutting. All of these factors increase the cost of platform removal.

The MMS report provides a detailed list of the assumptions made by TSB in developing these decommissioning cost estimates, as well as the algorithms used in their calculations. These assumptions and algorithms can be used to develop similar decommissioning estimates for other deepwater platforms located in the POCSR and GOMR.

Decommissioning Methodology Evaluation and Comparison

A key objective of the MMS study was to provide a quantitative analysis comparing the three decommissioning methodologies for each of the platform removal scenarios. In order to perform this analysis effectively, categories were developed and a ranking system was employed to facilitate this task.

Evaluation Category Selection and Ranking. Issues that influence decommissioning method selection were categorized and ranked in order of importance from 5 to 1 (5 being the most important). The evaluation categories used in this study were (1) Safety, (2) Technical Feasibility, (3) Environmental Impacts, (4) Permitting, (5) Disposal Options, (6) Cost, and (7) Scheduling.

Safety was considered the most important of the seven evaluation categories, in that the method ultimately selected must not present any excessive or unknown safety issues to personnel. The three methods selected have all been deemed safe; however, ultimately (because of the work involved in accomplishing the platform decommissioning) one method will be safer than the others.

Technical Feasibility and Environmental Impact were considered as the next most important categories and thus were given an equal rank of 4. Technical Feasibility considers the work required in planning, and executing the deck and jacket removal. Cutting, handling and dismantling of the jacket was factored as an integral part of the method evaluation. In the case of the particular method evaluated, there are no major technical issues. However, this is not always the case.

Air/water pollution and impact on the local or nearby marine life was considered in evaluating the decommissioning methods. Ultimately, the method selected should pose the least practical impact on the surrounding environment.

The Permitting and Disposal Option categories were ranked as having average importance in the evaluation. Regardless of the method selected, each will require permits from various agencies with numerous requirements. Due to the large quantities of material being handled, the Disposal category was deemed more important than Cost and Schedule.

Cost is a significant factor in evaluating and selecting the decommissioning method. However, it was considered that the aforementioned factors should carry more weight in selecting the method to use. If the method selected happens to be the least expensive method it should be justified by the higher ranked categories such as Safety and Environmental Impact and not by cost alone.

Scheduling was considered as the category that least influenced the decommissioning methodology selection. The operator can begin planning to decommission the platform before it ceases production. There are certain tasks that can be accomplished prior to cessation of production that will not affect the critical path. However, because of the complexity of platform removal, permitting requirements, and lack of local infrastructure in the POCSR, it is recommended that planning begin at lease three years prior to commencing any offshore decommissioning work.

Decommissioning Evaluation. Using the categories described above, each decommissioning method was compared to the other two and ranked 1, 3, or 5 (5 being the best case method). The ranking for each method was then multiplied with the weighted value for each task. The resulting numbers (shown in *italic*s) were then added to determine the total score. The decommissioning method with the highest values is considered to be the best option. Table 3 presents the results of this evaluation.

The table and numerical rating system is not specific to the POCSR except for permitting. The other categories will tend to have the same ratings regardless of location.

Category Evaluation Discussion. Complete Removal, Partial Removal, and Remote Reefing were found to be equally comparable in all decommissioning phases except jacket removal. The following discussion highlights the issues where the differences exist between the three decommissioning methods categorically.

Safety. Safety is considered the most important factor in selecting the decommissioning method. Safety issues evaluated are directly related to the complexity of the work, duration to complete the work, and equipment required.

Partial Removal was considered as the safest of the three methods. This method considers cutting the jacket at (-) 85 below the waterline, a depth commonly accessed by commercial divers. Since explosives are not used, the local marine life is not affected; in fact, a major portion of the habitat is maintained.

Remote Reefing was rated in the middle of this category, in that divers are used longer and at greater depths and the local marine environment is affected. Divers will assist attaching bouyancy bags to the jacket. This extra work requires the use of divers at depths greater than the (-) 85 feet (Partial Removal) for longer periods of time. Additionally, the explosives used to sever the piles will greatly affect the local marine habitat.

Complete Removal is deemed the least safe method due to large the amount of work required to remove the jacket. The HLV handles, cuts, lifts, and loads the jacket in many sections. This will require extensive of personnel. If the jacket were cut up in-situ, the safety issue would be even more of a factor.

Lloyd’s Register report (Lloyd’s July, 1997) concluded, “the results show risks to safety are approximately 50% higher for the total removal compared to the partial removal options. This is mainly due to the higher exposure of the workforce to offshore hazards during the total removal of the jacket.” The Lloyd’s study considered North Sea Platforms in water depths less than 400 feet. For the platforms included in this study, the risks may be even higher in that the exposure of the workforce to offshore hazards is greater for the deepwater platforms. In addition, the differences between deepwater complete removal and partial removal are much greater that the conventional method analyzed by Lloyd’s.

Technical Feasibility. Issues considered for this category are the planning, engineering and execution required to complete the jacket removal. Partial Removal was considered the most feasible method. Cutting the jacket at the specified location only requires the use of divers for a short period of time at the specified depth.

Remote Reefing is more challenging in that ballast calculations are required to determine the additional buoyancy needed to re-float the jacket. Deballasting the jacket at the reef site will also need to be planned and engineered.

Complete Removal was ranked as the most technically challenging method. A detailed engineering study is necessary to determine how the jacket will be cut (size, weight, and location). Locations to cut the jacket are then established based on the jacket sections configurations. Rigging and handling the jacket sections will at times be very challenging to the HLV. Removal *in situ* would be more formidable.

Environmental Impact. Three issues were considered for this category: air pollution, use of explosives, and impact on the attached flora and fauna and other marine life. Reefing jackets in place (*in situ*) has the least impact on the environment. The marine equipment utilized is on the job for site less time than for the Complete Removal scenario. In addition, the work is performed in one place, unlike in the Remote Reefing scenario. This avoids the emission of pollution in other areas outside the general platform location (as found in the Complete Removal and Partial Removal scenarios). The less time the equipment is on site, the less impact it will have on the environment.

Explosives are not used to sever the piles in the Partial Removal method, in that the jacket is not removed. The Complete Removal and Remote Reefing methods sever the piles with explosives, which in turn affect the local marine habitat, killing marine life in close proximity to the jackets during detonation. Remaining marine life is also affected since their habitat has been removed. By reefing in place (Partial Removal), the artificial reef environment created when the platform was first installed is preserved. Furthermore, the additional jacket piece may provide the right conditions to enhance the current artificial reef.

Permitting Requirements. Issues considered in evaluating this category were the number of agencies involved and the process by which the method will be permitted. In the Gulf of Mexico, the MMS Regional office is the lead agency by which the platform decommissioning method is approved. More agencies (federal, state, county, etc.) and special interest groups are involved in the Pacific OCSR. In the POCSR, the Complete Removal method is the permitting mechanism identified to be most straightforward in accordance with existing regulations. Partial Removal and Remote Reefing requires that a reef program (similar to the Texas or Louisiana Artificial Reef Program) be established and the guidelines approved.

Remote Reefing can place the jacket at a designated reef site. For this reason it was scored in the middle. Partial Removal will require that the platform location be designated as a reef site. Texas and Louisiana require reviewing the reef according to guidelines and ultimately decide if the platform site is acceptable. The study scored Partial Removal as the method that will be harder to permit, unless high value is placed on issues such as environmental impact.

Disposal Option. The amount of material being removed and taken to shore was the issue in evaluating this category. While Partial Removal and Remote Reefing send only the topsides to shore, Complete Removal sends the topsides and all of the jacket and conductors to shore for recycling. Partial Removal was given a high score of 5, while Remote Reefing scored next. Complete Removal will require the most effort to dismantle and recycle the platform. For this reason, Complete Removal scored the lowest in this category.

Cost. Complete Removal, Partial Removal, and Remote Reefing costs for the Hidalgo, Gail, and Harmony platforms are listed in Table 2.

Partial Removal is the least expensive of the three methods and thus scored the highest. Since Remote Reefing is very close to Partial Removal, a score of 4 was assigned. As expected, Complete Removal (the most work-intensive method and thus the most expensive) scored a 1.

Schedule. Assuming that three to five platforms will be decommissioned concurrently, the schedule will influence the method selected. Partial Removal can be completed in the least amount of time (20 days per platform) and thus scored a 5. Remote Reefing was assigned a score of 4 in that the time to remove the platform is very close to Partial Removal (23 days). Complete Removal scored a 1, in that it takes as least three times longer than the other two methods.

Heavy Lift Technology

The load weights associated with deepwater platform installations and removals limit the number of existing heavy lift vessels (HLVs) that can be used in these operations. The MMS study provides a review of conventional HLVs that can be used to decommission deepwater platforms like Hidalgo, Gail, and Harmony. Also included are evaluations of alternative heavy lift vessels currently being developed with an assessment of the potential to apply them to the removal of deepwater platforms.

Standard Heavy Lift Technologies. A limited selection of heavy lift vessels (HLVs) working around the world today can perform the tasks required for removing deepwater platforms. Table 4 presents a summary of the HLVs available that can perform the lifts required for the platforms included in this study.

HLV(s) selected should have the capacity to lift the largest module and jacket sections. The heaviest module lift for the Hidalgo and Gail platform removals is on the Gail platform (1,790 ton dry lift weight). The heaviest module on the Harmony platform weighs 1,320 tons (dry lift weight). Additionally, if the jacket is to be removed in as large pieces as possible, the resulting jacket sections will weigh more than the heaviest module.

For the Complete Removal scenario, a Hermod- or Balder-type SSCV was used to derive the decommissioning cost estimates for the Hidalgo and Gail platforms. The Thialf or the Siapem 7000 was selected for the Harmony Complete Removal scenario.

The use of SSCVs to remove the platforms is not the only option. TSB evaluated the feasibility of removing the platforms using 2,000-ton capacity tugs in the Partial Removal and Remote Reefing alternative removal methods.

Any HLV considered will need to be modified to meet local air emission requirements. This could be potentially very costly in that a catalytic converter may have to be adapted to each engine above 5 hp. Dynamically Positioned Vessels will most likely require more retrofitting than anchored vessels. These additional costs for DPV could discourage their use. Most vessels listed in Table 4 have DP capabilities but are typically anchored for decommissioning projects. This will be an issue in their certification.

Alternative Heavy Lift Technologies. The following section offers a summarized review of alternative heavy-lift technologies currently being developed for offshore platform installations and removals.

Versatruss. Versatruss is a balanced, symmetrical, underside lift concept that makes use of a truss formation to lift a heavy load. In application, this system employs three readily available components:

- Standard cargo barges, which provide the lifting platforms
- Steel A frames, which provide the structural support
- Hydraulic winches, which supply the lifting force

Booms and the deck structure form the upper portion of the truss; the lower segment is created by Versatruss rigging and a tension cord inserted between the platform legs. This arrangement results in an extremely efficient distribution of load into the deck. Once attached to the deck, synchronized winches are engaged, causing the barges to move together and shortening the lower span of the truss. When this happens, the booms rotate on their heel pins, increasing the boom angle and generating vertical lift. The process is fully reversible at any time, with lifting or set-down taking a relatively short period of time.

Because of the basic nature of this system, it can be designed to accommodate the largest topsides currently in existence. Once lifted, topsides can be:

- Towed to shore (or to another location if re-installation is the goal) in a catamaran configuration
- Lowered onto a cargo barge
- Lowered onto a cargo barge and unhooked from the Versatruss system

The Versatruss system has been used successfully in several of topsides removal and installation projects. The largest of these lifts were the removal of a 1,225-ton deck from Amoco's Eugene Island 367 platform in August 1997 and the installation of a 5,330 tonne topsides for Chevron in Lake Maracaibo, Venezuela, in September 2000.

During the Lake Maracaibo platform installation project, planned Versatruss applications included the transportation and installation of jackets and topsides for three platforms. Although the topsides installations proved successful, during the transportation of the Versatruss jacket installation system to Venezuela, the system tore itself apart and was lost *(Offshore Enginee*r, Oct 2000).

Versatruss has been effective in increasingly larger topsides removal and installation applications, but, to date, has no proven solution for the removal and/or transportation of jackets.

Versatruss Usability Evaluation. The Versatruss heavy lifting system is a proven, efficient method for removing and installing topsides. Multi-sheave blocks can minimize winch loads, and multiple booms and connection points give it redundancy not found in the other alternative HLVs. Additionally, there is no theoretical limit to the load capacity of this system. However, the Versatruss system is not will suited for removing jackets. The Kinematics of the system make it difficult to provide a jacket lifting capability that would be effective in practical applications that require lifting jackets out of the water. Therefore, for Complete Removals, another HLV will be needed. Nevertheless, the Partial Removal and Remote Reefing operations might significantly benefit from the use of the Versatruss system.

GM Heavy Lift. The GM Heavy Lift vessel (GMHL), developed by ProSafe and the engineering company Global Maritime Heavy Industries (GMHI) uses existing, proven technology in a new way. The design uses an existing semisubmersible with a U-shaped extension that can remove a platform's topsides in a single lift. The extension is lowered below the bottom of the topsides by deballasting, positioned under the topsides and raised to a point where the topsides can be secured to the U-shaped extension. Once secured, the topsides is lifted off of the jacket and can then be moved to shore or set onto a cargo barge.

The GMHL is designed to lift loads up to 12,000 tonnes; the system itself displaces 40,100 tonnes The GMHL does not have a self-contained propulsion system; it needs to be towed by tugboats. It offers multi-purpose capabilities, in that it can house crew and equipment for topsides removal preparations, offer a power supply for the crane and other removal equipment, and support remotely operated vehicle (ROV) operations. Additionally, the GMHL does not need to be anchored due to the inclusion of a dynamic positioning system.

GM Heavy Lift Usability Evaluation. The GMHL is a good alternative to removing the topsides in one lift. However, preparation costs will increase if the GMHL is used as an MSV to prepare the platform removal. Also, upon loading the topsides, the GMHL would have to offload them either onto a cargo barge or at the onshore dismantling yard.

The GMHL may not be as efficient as an SSCV when moving the jacket or handling the jacket and the cut sections. There exists the possibility that the GMHL may be competitive when complete removal in-situ is required. However, the daily spread rate will have to be significantly lower than a SSCV’s day rate if the GMHL is to be considered a viable alternative HLV.

Pieter Schelte. The Pieter Schelte, designed by Excalibur Engineering, BV, is a platform removal and installation vessel formed by joining two large tankers together to form a stable platform. Topsides and jackets can be removed in discrete single lifts and transported to shore or to another location.

The design of the HLV ties together two large tankers at the stern, leaving the bow open to accept extremely large topsides. The vessel deballasts itself below the deck, raises (ballasts) to a point where the jacket can be secured to the vessel, and further ballasts to raise the topsides off the jacket.

The rear of the vessel includes a lifting arm that is raised above the jacket (once the topsides is removed and the piles have been severed). Once in position, rigging is lowered and attached to the top of the jacket, secured, and the jacket is raised to a point where it can be pulled over onto the jacket storage section of the Pieter Schelte. The vessel then moves to shore or to another offshore location for offloading and disposal or re-installation.

This Pieter Schelte can be used for decommissioning operations by lifting topsides up to 48,000 tonnes (approximately 53,000 short tons) and removing jackets up to 25,000 tonnes (approximately 28,000 short tons).

Surveys of short-listed tankers are currently underway. Once these tankers are selected, detailed vessel engineering will commence. The lift system conceptual engineering is currently being completed; detailed engineering will commence in late summer 2000. Per the current design and construction schedule, this system will be completed and operational by the 2003 North Sea summer season.

Pieter Schelte Usability Evaluation. The Pieter Schelte heavy lift vessel offers a good alternative to lifting the topsides in one unit. Unlike the HLV alternatives described to this point, the Pieter Schelte does not have to offload the topsides before lifting the first jacket section. Additionally, jacket cut sections could be skidded to the back of the vessel, allowing it to lift the remaining jacket portion to be immediately towed to shallow water to repeat the jacket removal process.

However, the Pieter Schelte may be a very expensive HLV to fabricate and maintain, and its day rate may potentially be higher than that of standard HLVs.

Marine Shuttle. The Marine Shuttle, designed by Marine Shuttle Operations, Inc. (MSO), is a steel hull U-shaped vessel designed for the transportation, installation, and removal of large offshore structures weighing up to 22,000 tons (using the ballast system). The structure comprises sections of tubulars 10 meters in diameter; tied directly to ballast tanks and ballast pumps. Water is pumped in during ballast operations and dumped for deballasting. This structure is unmanned and is not self-powered.

Topsides removal is completed by deballasting the Marine Shuttle along a flat plane corresponding to the water surface, and then maneuvering the structure to a position directly below the topsides. The Marine Shuttle is then ballasted (raised) to a point where it can be attached to the topsides. Once connected, the topsides can be towed to shore or offloaded onto a cargo barge.

Jacket removal techniques use the Marine Shuttle in a slightly different way. The open portion of the U-shaped is deballasted to tip over (dive) below the waterline. The structure is then positioned over the top portion of the jacket and attached to the jacket legs. Piles are severed either from the sea floor (depending on jacket size) or at the required water depth depending on which removal alternative is selected. The Marine Shuttle is then ballasted (raised), carrying the jacket (or the top jacket section) with it. The jacket (or jacket section) is then towed to shore.

The Marine Shuttle can be used during decommissioning operations by lifting topsides and jackets up to 22,000 tons.

The Marine Shuttle is expected to be ready by 2002/2003, depending on driving market factors.

Marine Shuttle Usability Evaluation. The Marine Shuttle heavy lift vessel offers a good alternative to lifting the topsides in one unit. However, it will have to offload the topsides either on to a cargo barge or onshore before it can continue working on removing the jacket.

For jacket removal operations, the Marine Shuttle must dive to attach to the jacket and rise to the surface for transport or offloading. In that deepwater platforms have jackets that exceed the Marine Shuttle's maximum load capacity, this process of deballasting and ballasting will have to be repeated multiple times for complete jacket removals. Therefore, moving and handling the jacket sections with the Marine Shuttle may not be as efficient as standard jacket removal techniques using SSCVs.

MPU Heavy Lifter. The MPU Heavy Lifter, built by MPU Enterprise, AS, is a U-shaped concrete hull unit with 4 columns, 2 hydraulic-operated truss-type steel lifting frames with a large underwater body and a small water plane area. The MPU has no propulsion system; therefore, it needs to be towed by tugboats. Travel speed is approximately 3-4 knots.

The MPU has been developed for the removal of topsides and jacket structures using single-lift technology (lifting by ballasting/deballasting the vessel). The MPU is currently in Phase 3 of its development. Phase 2 results show that the system is feasible and well suited for topsides and jacket removal.

The cost to fabricate the MPU (including engineering) is currently estimated at $70 million. The fabrication time for this vessel has been determined to be 14 months (start to finish). Based on an October 25, 1999 press release, MPU construction is scheduled to begin in summer 2000.

MPU Heavy Lifter Usability Evaluation. The MPU heavy lift vessel offers a good alternative to lifting the topsides in one unit. However, it will have to offload the topsides either on to a cargo barge or onshore before it can continue working on removing the jacket.

The MPU Heavy lift vessel current design parameters are based on North Sea platform designs. The deepwater platforms considered in this study are installed in water depths up to three times as deep as in the North Sea. Moving and handling the jacket sections with the MPU may not be as efficient as standard jacket removal techniques using SSCVs.

John Gibson Strand Jacks. John Gibson Projects Limited (JGP) offers a range of standard strand jacks that can extend the lifting/lowering capacity of one or all of the aforementioned alternative HLVs to 300 meters and beyond. This technology has proven extremely effective in tension-bridge construction projects, and is now being applied to offshore platform installations and removals.

The John Gibson Strand Jacks (JGSJs) include: a range of seven standard strand jacks (safe working capacities from 30 to 750 tonnes per jack); self-contained, diesel-driven power packs; cable handling and storage systems; and central control and monitoring capabilities. Conceptually, JGSJs would be used in conjunction with either the Marine Shuttle, the MPU, the GM Heavy Lift vessel, or the Pieter Schelte. These vessels can provide the platform by which the JGSJs are set. JGSJs could potentially enhance the jacket removal capabilities of any or all of these systems.

John Gibson Strand Jacks Usability Evaluation. John Gibson Strand Jacks might allow many of the alternative HLVs described in Section 8.2 to overcome many of their jacket removal limitations. JGSJs are proven to be reliable, but more investigations are required as to how these units can be used efficiently for deepwater platform removal operations.

Buoyancy Devices. Two types of buoyancy devices exist which must be reviewed: buoyancy bags and the controlled variable buoyancy system.

Buoyancy Bags. Buoyancy bags, manufactured by companies like Seaflex Ltd., are inflatable subsea buoyancy systems that can be attached to jacket members, conductors or pipelines. Once attached and inflated, these units can lift sections (or, in the case of jackets, potentially the entire structure) to the surface. The bags are offered in either open-bottom or fully enclosed configurations. These units can be connected to piles or conductors by using divers or remotely operated vehicles (ROVs).

These units have proven to be a successful lifting alternative in North Sea pipeline removal and maintenance operations. Current stock exceeds 3,000 tonnes lift capacity. Buoyancy bags are inexpensive to fabricate and maintain. However, inclimate weather conditions can create lifting variables that could potentially create difficulties for the jacket-handling vessels in raising the jacket. Movement created by underwater currents or uneven air expansion inside the bags could make it difficult to ensure that the jacket does not surface directly underneath the buoyancy bag-handling vessel or another on site vessel.

Controlled Variable Buoyancy System (CVBS). The Controlled Variable Buoyancy System (CVBS) is a patented concept being developed to provide an innovative and cost effective means of offshore structure removal. It does this by providing buoyancy that is attached to strategic points on the structure. The magnitude of buoyant lift can be closely controlled throughout all stages of the removal operation. The CVBS consists of groups of buoyancy chambers, clamps, inflatable air bags, pipework, valves, and a sophisticated control system. A group of chambers equipped with clamps, local controls and piping systems is referred to as an Intelligent Buoyancy Unit (IBU).

An Intelligent Buoyancy Unit consists of 4 no. 2.5m OD, 16m long shells. Three of the shells are perforated with a number of holes to allow water to flood freely in and out of the shell, and one of the shells is solid. The perforated shells have a domed end at the top fitted with an insert suitable for bolting on pipework and valving.

The main body of the shell is 20mm thick and the domed ends are 40mm thick. The shell will be filament wound with continuous glass fiber reinforcement. The shells are held in position and connected to the jacket leg via 2 friction clamps, which are hinged to assist in the installation procedure. A steel band is fixed around the shell and is then connected into the main body of the clamp by means of stiffener plates. Each clamp has stud bolts that lock into position on closure. With the clamp closed, using a hydraulic cylinder, a work-class ROV will torque each of the studs thus securely fixing the unit to the leg.

The control system consists of the following:

- Master Control System (MCS). The Master Control System is located remotely onboard the Multi- Purpose Support Vessel (MSV) or Diving Support Vessel (DSV) and communicates with the Master Control Module via a radio telemetry link.
- Master Control Module (MCM). The unit is located on the structure to be moved. It is PLC based and is connected to each of the IBU units. This allows the

Master Control Module to control the IBU unit Inputs and Outputs, valve operations, reading pressure values, and valve operation status information.

- Intelligent Buoyancy Unit (IBU) Control Pods. These pods contain all the electronics necessary to control valve operations and to read back data from pressure transducers.

A trial lift using one buoyancy tank to lift some 70 tonnes from the seabed in 50 m of water in Scotland will be undertaken during November 2000. The trial will incorporate the full control system, which will be tested during the trial operation.

Buoyancy Devices Usability Evaluation. Buoyancy bags provide an efficient alternative lifting systems for pipelines, but the system is yet to be proven to be able to lift items (i.e., jackets and/or jacket sections) of any considerable size. While the Controlled Variable Buoyancy System (CBVS) might be able to overcome some of the challenges presented by buoyancy bags (i.e., better control over the lift), this technology has yet to be proven in field tests. Accordingly, these buoyancy devices are not considered feasible alternative lifting technology for this study.

Heavy Lift Technology Evaluation Results. Many of the alternative heavy-lift technologies reviewed may someday prove to be safer, more cost-effective ways to remove topsides and jackets. The designed load capacities for many of these systems are more than adequate for the topsides associated with deepwater platforms. However, deepwater jacket removal tends to be problematic for all alternatives reviewed (not considering the possibility of incorporating John Gibson Strand Jacks into the design of these vessels).

Only the Versatruss deck-lifting system has been used successfully for offshore platform removal operations; the other systems are in various stages of development and testing. Additionally, the idea of considering any of these systems as the primary option for removing the Hidalgo, Gail, and Harmony platforms could potentially create scheduling problems if the systems are not ready by the time these platforms are ready to be decommissioned.

As a result, the standard, proven heavy lift vessels included in Section 8.1 are the most reliable heavy lift options currently available and have been used to develop the cost estimates included in this study.

Severing Technology

For any cutting technique to be effective, it must be:

- Safe
- Reliable
- Repeatable
- Flexible and adaptable under field conditions
- Environmentally sensitive
- Economical

The cutting techniques considered are grouped into two general categories: explosive and non-explosive. Available explosive methods are bulk charges, configured bulk charges, and shaped charges. Current non-explosive methods applicable to this study include diamond wire, mechanical cutters, and abrasive slurry cutters.

Explosive Methods. Explosives are widely used to decommission platforms because they are safe, reliable, and cost effective. The use of explosives reduces the amount of time divers are used during the cutting process, thereby minimizing human risk. Their reliability has been established by the fact that they have been successfully employed to remove over 930 platforms in the Gulf of Mexico to date. Additionally, the cost of severing piles and conductors is generally less than 1% of the total platform removal cost. Time is the driving cost factor when discussing severance; delays in vessel spreads are the primary reason for cost overruns. A failure in the complete severance of a pile or conductor is usually charged to the owner of the platform. These costs can be enormous, as time and material rates for large crane vessels can exceed $500,000 dollars per day.

Use of Explosives in Deep Water. Explosives have been used in deepwater in a variety of applications. Primarily, the work conducted relative to offshore structures has been for wells. Conductor wells have been successfully severed in water depths exceeding 2,850 feet. Explosive charges have been set using divers, remotely operated vehicles (ROVs), atmospheric diving systems (ADSs), and off the end of drill pipes from drilling vessels (with the aid of underwater cameras).

Effect of Water Depth on Explosives & System Selection. The explosive selected for deepwater applications must be one which is not desensitized by water, components do not separate under pressure, and does not become more sensitive with the expected increase in hydrostatic pressure. This would rule out many of the binary explosive mixtures and blasting gels.

It may become necessary to place the detonator underwater. Most common detonators are not designed for use in water depths over 400 feet; however, seismic detonators can withstand depths of 5,000 feet or more.

Effect of Water Depth on Cost. The effect of water depth for charges that weight under 100 pounds does not significantly change. These charges are lowered with rope, which is a minimal cost factor. The detonating cord is also a minimal cost component. Significant cost increases are relative to charge size and weight. Setting a standard Shock Wave Enhancement Device (SWED) device weighing less than 600 pounds only requires a ¼-inch wire cable. However, the larger the piles and the corresponding increase in charge weight would require larger cable, and increasing cable diameter to over 1 inch can have a significant affect on overall cost.

Cost Increase due to Target & Charge Diameter. When using a SWED-type device for large diameter piles, size and weight becomes relative – bigger is not necessarily better. The SWED devices are constructed with large-diameter plates in varying thickness. As plate diameter and thickness increases, costs escalate due to difficulties in machining and handling the device. Plate diameters over 6 feet are considered special order and require a long lead-time.

The equipment just to handle these sizes and weights is expensive. Cost reductions could be achieved by forging these devices or certain components. Explosive costs increased considerably in examining deepwater platforms because the weight required to sever the target reliably is doubled and tripled from the standard 50 pounds presently used in the Gulf of Mexico.

The variables that affect cost increase exponentially when discussing shaped charges. However, of all the uses of explosives, the shaped charge has developed the most scientific and practical applications.

Non-Explosive Methods. Non-explosive methods presently used consist of diamond wire, abrasive (slurry) cutters, mechanical cutters, and oxy-arc torch (diver cutting).

Diamond Wire Cutting. The diamond wire cutting system (DWCS) is an external cutting tool that can be used to cut jacket legs, piles, and diagonal members above and under water. Divers or a remotely operated vehicle (ROV) can install the DWCS.

Diamond wire cutting has been used since the early 1990’s in the North, Adriatic, and Red Seas. Since then, the DWCS has been used for the removal of offshore platforms, caissons, conductors, risers, etc. However, until recently, the DWCS had not been used in the Gulf of Mexico (GOM). It was last used in the GOM to externally cut 82” and 48” caissons installed in 120 feet of water.

Benefits of this cutting tool over other cutting methods are many. There seems to be no limitation in the size of the cut or material to cut, as long as the cutting tool can be fixed to the cut member. Water depth may not be an issue when using this tool; an ROV or diver wearing a hard suit can take and set the tool at the desired location. By-products generated by the DWCS are only the fine cuttings from the object being cut, minimizing damage to the environment.

Limitations of the DWCS are based on its external cutting design. If piles are to be severed below the mudline, jetting will need to be performed to allow the cutting device and frame to be attached to the pile. Additional jetting may be necessary depending on the size of the ROV or other subsea device being used to attach the unit. An additional limitation of the DWCS is its current control system.

Developments currently underway promise to overcome any limitations in the DWCS's present design. A sub-bottom cutter (SBC) is currently in development, which will facilitate cuts below the mudline. Additionally, a computerized cutting control system promises to provide faster cuts that are more successful in the near future.

Abrasive Cutting. Abrasive cutting employs mechanisms that inject cutting materials into a water jet and abrasively wear away steel . There are two types presently in use: high volume-low pressure and low volume-high pressure. The first type of abrasive cutter disperses high volumes of sand or slag mixed with water volume (80 to 100 gallons/minute) at relatively low pressure (4,000 to 10,000 psi). The second type of abrasive jet cutters use low volumes of garnet or other abrasive materials injected at the nozzle at relatively high water pressure (50,000 to 70,000 psi).

Limitations for both the internal and external abrasive cutters include uneven cutting, clogged hoses, and water depth limits. Limitations also include the minimum inside diameter that can be accessed approximately seven inches, combined with the outside diameter that can be cut. In shallow water depths, abrasive cutters have been proven to be an effective alternative to explosive pile severing. In some circumstances, conversations with abrasive jet contractors reveal the unsatisfactory use of these cutters in water depths greater than 400 feet. Improvements to the systems generally will eventually allow the abrasive cutters to work in deeper water depths.

There also exists the problem of verifying that the cut has been made when using an internal abrasive cutter. Unlike explosives, the conductor or pile often does not drop, confirming that the cut was successful. With an abrasive tool, the width of the cut is small and combined with the soil friction, a visual response generally does not occur. To verify the cut, the conductor is pulled with either the platform crane or hydraulic jacks. The lift force must overcome the conductor weight and the soil friction. At times, this force is many times more than the actual conductor weight. It is generally assumed that the cut is not successful if the conductor can not be lifted with a force two times the conductor weight. The abrasive cutting tool is either re-deployed to make another complete run, or explosives are used to complete the cut.

Mechanical Cutting. Mechanical cutting employs hydraulically actuated, carbide-tipped tungsten blades to mill through tubular structures. This method has been used most successfully on small-diameter caissons with individual wells and shallow water well-protector platforms with vertical piles.

Limitations for the mechanical cutter include uneven cutting (from lateral movement of uncemented strings), replacement of worn blades, larger lifting equipment necessary to set the system, and more time required to make each cut.

Severing Technology Evaluation Results. Explosives are predictable, flexible, and reliable. Current industry practice uses explosives to sever piles below the mudline at any water depth. Until other techniques provide the reliability and effectiveness of explosives, these methods will continue to be used for pile severing.

Abrasive and mechanical cutters are not as reliable as explosives to sever piles. Although they have been proven effective (generally on platforms located in relatively shallow water), deepwater simulation tests have demonstrated that there are a number of operational issues that need to be resolved for each of these alternative cutting methods. Additionally, there are more delays with these systems if they fail, and a complete cut during the first pass is less likely to occur than if explosives are used.

The DWCS is an alternative cutting tool that has great potential for deepwater use, specifically for severing jackets and pipelines. It is relatively easy to install (diver- and ROV-friendly) and current frame designs fit the pile sizes associated with the platforms included in this study. Although the DWCS might soon become a standard tool for efficiently severing piles, conductors, and pipelines, further testing is necessary before it can be considered a viable alternative cutting method for deepwater platform removals.

While some (or all) of these alternatives may someday provide a viable alternative to explosive pile severing, potential increases in cost and diver risk currently make these alternatives less attractive than explosives for the removal of deepwater platforms.

Subsea Technology

Due to the extreme water depths focused on in this study, several new subsea technologies were reviewed to provide alternative methods for assisting in pile severing and jacket cutting. These include advanced remotely operated vehicles (ROVs), hard-shelled diving suits, and directly operated vehicles (i.e., single-person submarines).

These devices would be employed to perform a variety of tasks at deeper water depths, including:

- Valve operation
- Cutting steel and fiber cables or ropes
- Operation of disc grinders
- Attachment of external cutting tools
- Hot tapping
- High-pressure water jetting
- Removal of cuttings from well heads
- Make and break hydraulic connections
- Bathymetric surveys
- Trench profiles
- Sub-bottom pipe tracking
- Video observation and still photography
- Tool-skid carrying capabilities

Remotely Operated Vehicles. Remotely operated vehicles (ROVs) are proven tools for safely operating in marine environments. The increasing need to be able to use these machines at deeper and deeper water depths is driving the development of advanced ROVs that can be utilized in deepwater platforms installations and removals.

The pile diameters associated with deepwater platforms is larger than standard platforms while pipelines are installed at greater depths; therefore, larger ROVs are necessary to handle equipment used to sever piles. Additionally, the pressure at these depths provides an additional challenge to ROV design.

An unit such as the Sealion MkII Heavy Work Class ROV, designed and manufactured by Techno Transfer Industries (TTI) and operated by Asiatic Racal Underwater Contractors (ARUC), is an example of an ROV which can currently operate in deepwater environments.

ROVs: Advantages. ROVs replace divers in extreme water depths, thereby allowing for safer deepwater operations. They can be fitted with cutting tools to sever pipelines or jacket members, and can also aid in installing external cutting tools. Finally, ROVs are not depth or dive-time dependent.

ROVs: Disadvantages. High fabrication, maintenance, and operations costs are just some of the disadvantages to using ROVs. Other drawbacks include:

- Larger umbilical and more power required
- Observations of working conditions are dependent on remote cameras
- Technical challenges
    - Operators must be highly skilled to operate these ROVs
    - Control systems are complex
    - Tether may create problems

Deepwater Diving Suits. In order to safely deploy divers at water depths exceeding 400 feet, diving suits used must meet the challenges of handling deepwater pressures while allowing divers to efficiently perform work in the deepwater environment.

Companies such as Oceaneering and Stolt Offshore, Inc. are currently using systems like the Hard Suit to perform work in deep water. The Hard Suit is a proven tool for deploying divers at water depths exceeding 1,000 feet. The suit has been used in approximately 30 actual offshore operations in the Gulf of Mexico and in Brazil; the maximum water depth for these operations was 1033 fsw. These suits are rated for a maximum water depth of 1,200 fsw with a normal dive time of 6 hours.

In order to minimize downtime, the Hard Suit is operated in pairs to provide a "standby" diver in case one of the suits is in need of service or repair.

Deepwater Diving Suits: Advantages. Deepwater Diving Suits a reable to deploy divers in water depths up to 1,200 fsw; they are designed to kneel, lay down, and even work with the diver's head below his or her feet; and they have been used successfully in a number of deepwater operations.

Deepwater Diving Suits: Disadvantages. Even with the most advanced diving suit, extreme water depths still pose a threat to divers. Additionally, deepwater diving suits have high fabrication, maintenance, and operations costs, and require highly skilled divers and above-water personnel to operate these suits**.**

Directly Operated Vehicles. As an alternative to ROVs or deploying divers in deepwater using hard-shelled diving suits, diving vessels (i.e., manned single-person controlled submarines) are currently being developed for deepwater operations. Also called directly operated vehicles (DOVs), these one-person submarines may someday prove to be extremely useful in deepwater decommissioning operations.

To meet the demand for vessels of this type, Nuytco, Inc. has developed the Newtsub Deepworker 2000, a one atmosphere, single person, under-sea work vehicle. This vessel is designed to be completely tetherless in normal operations and can be fitted with a fiber optic cable (approximately the size of a lead pencil in diameter) to transmit data to the surface. Because of its autonomous design, the Deepworker 2000 has very high power availability at the vehicle, coupled with directly operated, high performance manipulator capabilities. Additionally, this system can be deployed to a maximum water depth of up to 2,000 feet.

DOVs: Advantages. Using DOVs allows Operators to observe situations first-hand. They are self-powered, no tether is required, and have powerful lifting systems (lifts up to 150 lbs. at full extension). Finally, DOVs allow divers to access extreme water depths (up to 2,000 feet).

DOVs: Disadvantages. Highly skilled divers and above-water personnel are necessary to operate these vessels. As always, the use of a manned system places personnel at risk, and DOVs (like ROVs and deepwater diving suits) have high fabrication, operations, and maintenance costs.

Subsea Technology Evaluation Results. Remotely operated vehicles (ROVs) have been used successfully in a number of offshore operations for many years. Larger ROVs can provide the same key advantage of their shallow-water predecessors – decreasing the risk to human life. They can be fitted with a variety of cutting tools, assisting in external cuts at depths that are inaccessible to divers using conventional diving gear.

Hard-shelled diving suits and single-person diving vessels currently being developed and used can also be outfitted with these cutting tools and allow divers to access the depths defined as "deep water." While the major disadvantage of using these types of deepwater equipment is the fact that they still place human life at risk in deepwater environments, this fact is also their greatest advantage. They offer the ability to allow people to perform work first-hand at water depths exceeding 400 feet. An additional advantage of using the manned vessel is its ability to work without the constraints of a tether.

Conclusions

1. While a number of new technologies are currently being developed for the removal of offshore platforms, conventional removal technologies remain the best option for decommissioning deepwater platforms.
2. Existing heavy lift vessels such as the Thialf, Siapem 7000, Hermod, Balder, and DB50 are currently the most cost-effective and dependable topsides and jacket removal systems available. Additionally, explosives remain the safest, most dependable, and reliable severing technique available today.
3. Of the three removal techniques reviewed, Partial Removal was rated the highest in the majority of evaluation categories reviewed.
4. The Partial Removal scenario, combined with conventional heavy lift vessels, severing, and subsea technologies, is currently the safest, most cost-effective way to decommission offshore platforms located in deep water.
5. In that a number of the new technologies reviewed are close to becoming viable, an ongoing assessment of these technologies is required to remain abreast of the deepwater decommissioning state-of-the-art in the future.

Acknowledgements

We thank the United States Department of Interior Minerals Management Service for their support in the development of this study: Sharon Buffington as technical leader and Jon Smith and Glen Shackell of the Pacific Outer Continental Shelf Regional Office; TEC-Demex for providing all of the explosives data and report.

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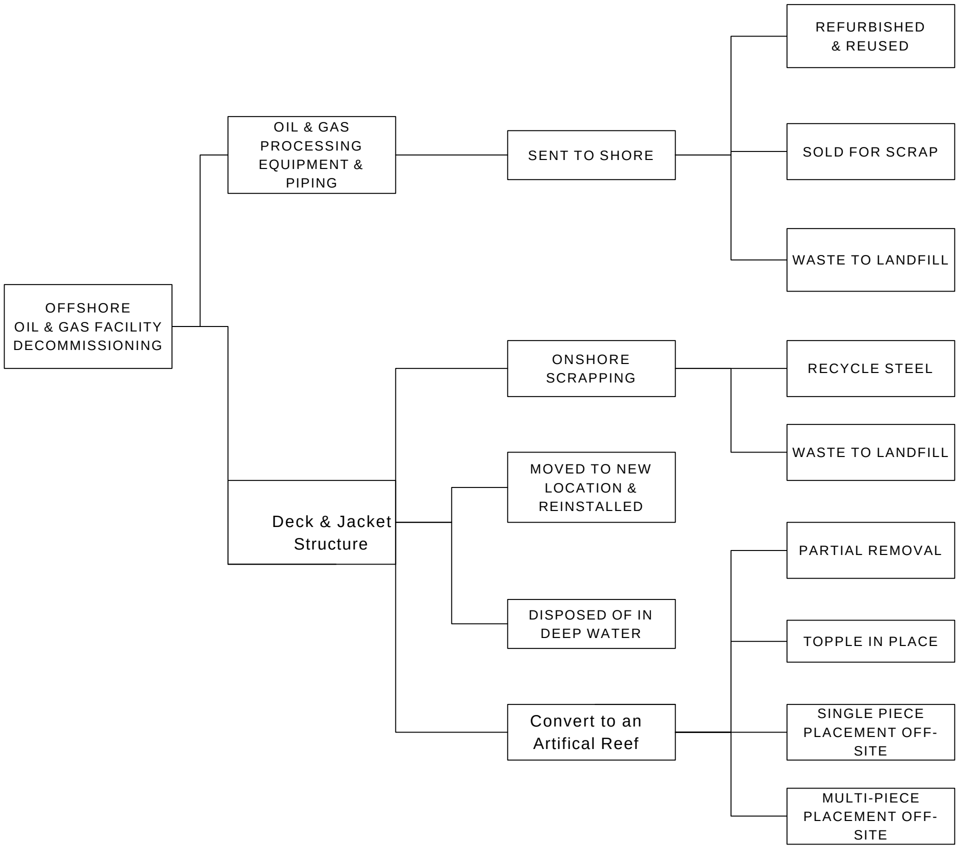

Figure 1. Decommissioning Decision Tree

Table 1 – Data Summary for Selected Platforms

Platform	WD (ft)	Number of Main/Skirt Piles (Outer Diameter)	Number of Modules	Number of Conductors	Number of Originating Pipelines
Hidalgo	430	8/8 (60”/72”)	7	10	2 (16”, 10”)
Gail	739	8/12 (60”/72”)	5	22	3 (8”, 8”, 8”)
Harmony	1,198	8/20 (72”/84”)	10	51	2 (12”, 20”)

Table 2 – Decommissioning Summary Results ($MM)

Platform	Water Depth (ft.)	Total Weight (tons)	Complete Removal	Partial Removal	Remote Reefing
Hidalgo	430	21,050	44	15	18
Gail	739	30,000	57	15	20
Harmony	1,198	65,050	123	20	35

Table 3 Decommissioning Method Evaluation

	Complete Removal	Partial Removal	Remote Reefing
Safety	(1)	(5)	(3)
(5)	*5*	*25*	*15*
Technical feasibility	(1)	(5)	(3)
(4)	*4*	*20*	*12*
Environmental impact	(1)	(5)	(3)
(4)	*4*	*20*	*12*
Permitting requirements	(5)	(2)	(3)
(3)	*15*	*6*	*9*
Disposal Option	(1)	(5)	(4)
(3)	*3*	*15*	*12*
Cost	(1)	(5)	(4)
(2)	*2*	*10*	*8*
Schedule	(1)	(4)	(5)
(1)	*1*	*4*	*5*
Rank total	**(11)**	**(31)**	**(28)**
Weighted total	***34***	***100***	***73***

Table 4 Heavy Lift Vessels Considered for Topsides/Jacket Removal

Operator	Vessel	Hull	Max. Lift (ST)
Heerema	Hermod	Semi	4000/ 5000
Heerema	Balder	Semi	3000/ 4000
McDermott	DB 101	Semi	3500
Heerema	Thialf	Semi	6600/ 6600
McDermott	DB 50	Mono Hull	4400
Saipem	Saipem 7000	Semi	7000/ 7000