An Assessment of Safety, Risks and Costs Associated with Subsea Pipeline Disposals

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Client MMS

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Title:

AN ASSESSMENT OF SAFETY, RISKS AND COSTS ASSOCIATED WITH SUBSEA PIPELINE DISPOSALS

Client: Minerals Management Services (MMS), Department of Transportation (DOT)

Client specification:

Prepare a study, which details the safety, cost and environmental risks associated with the various disposal options for pipelines in the U.S. waters

Summary:

See summary in Section 2.

Key words	Name	Signature
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1. INTRODUCTION

When a subsea pipeline reaches the end of its useful life, due to economic or mechanical integrity reasons, it must be abandoned or removed. If abandoned the subsea pipeline owner remains responsible for the pipeline even though it is not in service. Currently, subsea pipelines are de-inventoried and purged until the hydrocarbon levels are undetectable before abandoning them in place or the pipeline is de-inventoried and purged until the hydrocarbon levels are undetectable before recovering the pipe as scrap. The common practice in both the U.S. waters and the North Sea is to abandon the pipeline in place.

This report presents an overview of the current U.S. and International regulations and details the safety risks, environmental risks and costs associated with the various disposal options for pipelines, which are no longer in use. Scandpower Risk Management Inc. (Scandpower) of Houston, Texas carried out this study for the Minerals Management Service (MMS) and the Department of Transportation (DOT) Research & Special Programs Administration Office of Pipeline Safety (RSPA/OPS). Scandpower has subcontracted Global Industries to assist with identifying the removal technology and developing the cost estimates.

For this study the most common method of disposal for subsea pipelines, abandoning the pipelines in place, was used as a baseline and several removal options currently used around the world were compared with this base case. The disposal options used in this report are documented in "*The Abandonment of Offshore Pipelines Methods and Procedures for Abandonment"* by John Brown Engineers and Constructors (1).

2. SUMMARY

Regulations

Subsea pipelines in U.S. waters fall under the regulation of the Department of Transportation (DOT) Research & Special Programs Administration Office of Pipeline Safety (RSPA/OPS) and the Minerals Management Service (MMS) of the Department of the Interior (DOI). At the time this report was written no international rules/laws regarding the abandonment or removal and disposal of subsea oil and gas pipelines existed.

Safety and Risk

In general, this study shows that working accidents in connection with demolition activities dominate the risk to personnel. These activities include diving operations, work on barges with sea fastening and work onshore involving the cutting/disposal of pipe and materials. Barge work, including handling of pipes with marine growth and hydrocarbon residuals provide a large contribution to the total personnel risk.

The risk assessments demonstrate that pipeline removal options, as compared to in-situ (leave in place) and bury/trenching disposal options, carry a greater risk to personnel due to removal options having increased hands on involvement. As a result of these findings, in the event that pipeline removal is necessary, the extent of the work (hands on involvement of personnel) performed offshore either on a barge or during diving operations should be minimized. The increased use of ROVs and other remotely operated equipment can help to obtain this effect.

Even though there remain risks involved with the handling of equipment and pipeline sections, the overall risk to personnel due to pipeline removal operations is relatively small in instances where the use of remotely operated equipment is taken full advantage of and is suitable for the operation. Of the removal techniques studied, those involving reverse lay methods were found to be safer than those involving tow and sectioning methods due to the reduced number of subsea activities involved. The correct handling of pipe with corrosion resistant coatings and having a proper industrial process for materials separation will be essential to minimize the personnel risk during the final disposal phase, which is conducted onshore. Several proposals were made in this report to ensure the operations in the removal and final disposal phase are carried out with proper regard to safety.

Very few subsea pipelines in the U.S. waters (and internationally) have been removed. Therefore, no statistics or accident reporting is available for these activities.

Fault tree analysis was not completed since the nature of the events found during the hazard identification was not suitable for such analysis.

Cost

Removal of pipelines is a high cost operation with the costs dependant on the pipeline location. For example, recovery of pipelines on the west coast of the U.S. will result in high mobilization costs since the recovery vessels will have to be moved from their normal operating location to the west coast.

If all of the pipelines currently in service were to be removed and disposed of onshore after abandonment, the cost associated is estimated at 16.2 billion dollars. This assumes an average depth in the 200-500 foot range, the reversed lay methodology and that each portion of pipeline is approximately 4 miles long. The cost does not include transport onshore and any further processing or landfill cost. The burial/ trenching method of disposal is estimated to cost 1.6 billion dollars.

It is assumed that the cost for removal of abandoned pipelines will decrease if these types of activities are started. This is due to development in pipeline recovery technology.

Environmental Impacts

The impacts on the environment, especially the marine environment, from pipelines and cables left in place were found to be minor. This is based on the assumption that the prior to abandoning a pipeline in place, it has been purged and flushed to reduce hydrocarbon residue below detectable levels.

Mercury and cadmium, metals in pipelines and anodes, are believed to have the potential for a negative impact on the environment. However, estimated losses of mercury and cadmium from pipelines are responsible for only a small percentage of the total annual anthropogenic releases in U.S. waters. Significant environmental impacts from other elements found in the pipelines are not expected. In general, the adverse impacts on the marine environment due to the corrosion/erosion of pipelines abandoned in place are minor. The removal of the pipelines will only provide a marginal benefit due to a reduction in releases to the marine environment.

The recovery operations have a negative impact on the environment. The number of vessels and operating hours required to recover the pipelines will result in releases and emissions as well as disruptions to the area's marine ecosystems. Removal of pipelines demands extensive marine operations over a period of time. The energy saved by recycling the pipeline materials will fall short of the energy consumption by the recovery vessel during the pipeline removal operations. Compared with the abandon in place option, pipeline removal requires 70 % more energy.

Emissions to atmosphere are significantly higher for the removal options than the leave in place option. CO_2 emissions are about 120 times higher for removal than for leaving in place.

Even when considering theoretical "replacement emissions" the leave in place option has the lowest emissions for all type of gasses (3).

Overall conclusion

Currently, there are no regulations that require removal of subsea pipelines if they are not an obstruction to navigation. Based on the high costs for removing the pipelines, the personnel risk involved in the removal operations, the negative effect on overall emissions to air and the very limited reduction in discharges to sea, the overall conclusion is that it is better to leave the pipelines in place. If possible, re-use of the pipelines is the optimal solution.

3. ABBREVIATIONS

DOI	Department of the Interior
DOT	Department of Transportation
DP	Dynamic Positioning
GOM	Gulf of Mexico
IMO	International Maritime Organization
LC	The London (Dumping) Convention
LRA	Low Radioactive Scale
MMS	Minerals Management Service
NORM	Naturally Occurring Radioactive Materials
OSPAR	Oslo Paris Convention
ROV	Remotely Operated Vessel
SAFOP	Safe Operations study
UNCLOS	United Nations Convention on the Law of the Sea

4. OBJECTIVES

The objectives for this study are to present the disposal options for subsea oil and gas pipelines that have reached the end of their useful life, identify relevant regulations, and detail the safety hazards, costs and potential environmental impacts of each disposal option.

The removal methods considered were identified in the pipeline disposal study "The Abandonment of Offshore Pipelines - Methods and Procedures for Abandonment" performed by John Brown Engineers and Constructors Ltd. in 1997 (Ref. /1/).

The risk assessment is focused on personnel risk. Each option for pipeline disposal is split into different main activities, which are used as the basis for the risk assessments.

For the cost estimates, the complete disposal activity from pipeline removal to deposition from the barge to onshore is included. Further transport, processing of the pipe sections and cost in connection with landfills are not included in the cost estimates.

The pipeline disposal options are assessed with regard to the following environmental factors: Energy (consumptions and total energy impact), emissions to atmosphere, discharges to sea or ground, physical impacts/effects on habitat, aesthetic impacts, waste/resource utilization and littering.

Finally the pipeline disposal options are discussed with regard to technical feasibility.

The main focus for the study is safety and risk. The cost estimates and environmental assessments are less defined.

5. WORK DESCRIPTION/METHODOLOGY

The work was performed in the following steps:

1. **Document search/preparations**
   Relevant reports were reviewed, interviews with relevant personnel were conducted and preparations for hazard identification were conducted. Incident reports from both government authorities and company files were also reviewed

2. **Regulations**
   A thorough evaluation of relevant regulations, requirements, governing documents was conducted

3. **Identification of operations**
   The risk assessments are based on the study "The Abandonment of Offshore Pipelines - Methods and Procedures for Abandonment" performed by John Brown Engineers and Constructors Ltd. in 1997. The report is studied and additional new information was added

4. **Risk assessment**
   The risk assessment/hazard identification focused on personnel risk. However, a checklist, usually applied for marine operations, also covering operational aspects and potential equipment damages was applied for the review. This was done to reveal operational problems, which could eventually lead to a situation with increased risk for personnel

5. **Cost estimates**
   The different disposal options identified in the John Brown HSE report were assessed with regard to cost for operations in the U.S. waters (Gulf of Mexico, Pacific and Alaskan Waters). The complete disposal activity from removal to final deposition/ reuse is included in the estimates. Scandpower subcontractor Global Industries performed the cost estimates. Global Industries has experience in pipeline installation/ removal

6. **Environmental assessments**
   Pipeline disposal options are assessed with regard to the following environmental factors:

   - Energy (consumptions and total energy impact)
   - Emissions to atmosphere
   - Discharges to sea or ground
   - Physical impacts/effects on habitat
   - Aesthetic impacts
   - Waste/resource utilization
   - Littering.

   Qualitative assessments were made, with discussions of both the possible impacts to the environment and possible mitigating actions that could avert negative effects and promote positive benefits.

7. Feasibility of disposal options

Pipeline disposal options are discussed with regard to technical feasibility. These assessments are kept separate from the cost evaluations.

6. REGULATIONS

6.1 US Regulations

Pipelines in U.S. waters fall under the jurisdiction of the Department of Transportation (DOT) Research & Special Programs Administration Office of Pipeline Safety (RSPA/OPS) and of the Minerals Management Service (MMS) of the Department of the Interior (DOI). DOT regulations 49 CFR Parts 192 and 195, which cover transportation of natural gas and hazardous liquids respectively, do not address pipeline removal after decommissioning. They do require the submission of location information to the National Pipeline Mapping System.

Pipeline decommissioning and removal procedures required by the MMS are detailed in 30 CFR 250.1750 through 250.1754. The type and scope of decommissioning work to be performed on a pipeline is dependant on the time the pipeline is scheduled to be out of service. These requirements, found in 30 CFR 250.1006, are shown below in Table 6.1.

Table 6.1: MMS Requirements to Decommissioning Work on Pipeline

Time out of service	Action
1 year or less	Isolate the pipeline with a blind flange or a closed block valve at each end of the pipeline
More than 1 year, but less than 5 years	Flush and fill the pipeline with inhibited seawater
5 or more years	Decommission the pipeline according to 30 CFR 250.1750-250.1754

Current pipeline decommissioning regulations found in 30 CFR 250.1754 require a pipeline to be removed, rather than abandoned in place, when the Regional Supervisor of the MMS determines that the pipeline is an obstruction. If it is determined that a decommissioned pipeline must be removed, the requirements of 30 CFR 250.1752 must be met.

30 CFR 250.1752 states that "before removing a pipeline, you must":

A. Submit a pipeline removal application in triplicate to the Regional Supervisor for approval that includes the following information:

1. Proposed removal procedures
2. If the Regional Supervisor requires it, provide a description, including anchor pattern(s), of the vessel(s) you will use to remove the pipeline
3. Length (feet) to be removed
4. Length (feet) of the segment that will remain in place
5. Plans for transportation of the removed pipe for disposal or salvage
6. Plans to protect archaeological and sensitive biological features during removal operations, including a brief assessment of the environmental impacts of the removal operations and procedures and mitigation measures that you will take to minimize such impacts

7. Projected removal schedule and duration

B. Pig the pipeline, unless the Regional Supervisor determines that pigging is not practical

C. Flush the pipeline.

6.2 International Regulations and Guidelines

Relevant U.S. law determines the decommissioning and cessation activities in the U.S. waters. However, the U.S. authorities will consider certain international law, conventions and guidelines. There are a number of international regulations and guidelines, which cover decommissioning and cessation activities for offshore installations that has reached the end of its useful life. These rules/laws do not specifically cover pipelines as such, but the pipelines are either indirectly included, or in the process of being included. Some relevant considerations are described below.

The 1958 Geneva Convention and the Nations Convention on the Law of the Sea (UNCLOS)

Article 5 of the 1958 United Nations Geneva Convention states that all abandoned or disused offshore installations must be removed. This was adopted at a time when the only offshore installations were found in GOM and all of these in less than 30 meters of water and relatively simple construction. Along with the development of more sophisticated and extensive offshore structures came developments in international law, and in 1982 the United Nations Convention on the Law of the Sea (UNCLOS) recognized a softening of the absolute removal requirement. Article 60.3 of the UNCLOS states that

> "Any installations or structures which are abandoned or disused shall be removed to ensure safety of navigation, taking into account any generally accepted international organization. Such removal shall have due regard to fishing, the protection of the marine environment and the rights and duties of other States. Appropriate publicity shall be given to the depth, position and dimensions of any installations or structures not entirely removed".

The UNCLOS thus recognizes that in some instances removal of offshore structures will not be required and envisages a development of international standards in this respect.

IMO

Headquartered in London, the International Maritime Organization (IMO) sets the standards and guidelines for the removal of offshore installations worldwide. IMO is the competent international organization pursuant to Article 60.3 of the UNCLOS. In 1989, IMO adopted guidelines and standards for the removal of disused offshore installations and structures. The IMO Guidelines are not formally binding and are thus advisory in nature. They do not specifically pertain to pipelines.

The London (Dumping) Convention

The London Convention (LC) is based at IMO headquarters in London. The new "Guidelines for the Assessment of Wastes and Other Matter that may be Considered for Dumping" were finalized in September 2000. These guidelines have been reviewed by a LC Working Group and have now been adopted. The 1972 London Convention provided a generic guidance provision for any wastes that can be dumped at sea. These new guidelines provide specific guidance for different classes of waste, including platforms and other man-made waste.

OSPAR

In summer 1998 the Commission on the Convention for the protection of the marine environment in the North East Atlantic, OSPAR, reached agreement on banning the dumping of disused offshore installations at sea. Exceptions are granted for certain kinds of installations or parts of installations if an overall assessment in a specific case shows that there are significant reasons for disposal at sea. The OSPAR decision entered into force on 9 February 1999. The decision does not cover pipelines, but there is an ongoing discussion with regards to how to handle pipeline decommissioning in the future.

7. PIPELINE DATA

The current pipeline mileages for the U.S. Gulf of Mexico waters, continental U.S. Pacific coast waters and Alaska waters have been estimated by using information provided by the MMS. These pipeline length estimates, totaling 33,291 miles, are given in diameter (inches) vs. length (miles). The estimates below are separated by Regional demographics.

Table 7.1: Estimates of Pipeline Mileage in the Gulf of Mexico

Pipeline diameter (in)	Length (miles)
< 4"	2,683
4" to 12"	20,002
14" to 16"	2,874
18" to 24"	4,612
26" to 30"	1,674
> 30"	1,055

Table 7.2: Estimates of Pipeline Mileage in West Coast Waters

Pipeline diameter (in)	Length (miles)
< 4"	0
4" to 12"	61
14" to 16"	108
18" to 24"	52
26" to 30"	10
> 30"	0

Table 7.3: Estimates of Pipeline Mileage in Alaska Water

Pipeline diameter (in)	Length (miles)
< 4"	0
4" to 12"	150
14" to 16"	0
18" to 24"	10
26" to 30"	0
> 30"	0

According to MMS data, the majority of pipelines (98+%) are in the Gulf of Mexico waters.

8. DISPOSAL OPTIONS

8.1 General

The disposal options are summarized from the report titled "Abandonment of Offshore Pipelines Methods and Procedures for Abandonment" by John Brown Engineers and Constructors (Ref. /1/).

The principal disposal options for offshore pipelines are:

- Leave in place
- Bury/trenching
- Removal by reverse lay barge recovery
- Removal by reverse reel barge recovery
- Removal by long section barge recovery
- Removal by tow recovery
- Removal by short section recovery
- J-lift recovery.

The types, sizes and services of pipelines in the Gulf of Mexico and West Coast waters are varied. The water depth, seabed terrain and geology also vary which will effect the disposal options that might be used when abandoning a pipeline. Pipelines that might require abandonment may be summarized as follows.

- Trunk lines
- Inter-field lines
- Flow lines
- Service lines and umbilicals.

Trunk lines may generally be described as long sections of large diameter pipeline laid from producing fields offshore to tie in points with onshore pipelines. This study focuses on the subsea offshore portions of the trunk lines. Trunk lines in the Gulf of Mexico are typically 16"-30", although a few are greater than 30" in diameter. Trunk line lengths vary from a few miles to more than 100 miles. As field development in deeper waters of the Gulf of Mexico continues, trunk lines are being extended to pipeline production from locations farther from shore.

Inter field lines are typically pipelines between offshore platforms within a field or lease blocks. Inter field pipelines usually range from 4" to 16" and transport production fluids (gas, oil, condensate or water) between platforms. Inter field pipelines may transport single phase or multi-phase fluids. Typically, inter field pipelines are 10 miles or less in length.

Subsea flow lines transfer well production from a subsea wellhead to a platform. Subsea flow lines are typically 2" to 8" in diameter and run short distances.

Current practice for most pipelines in the Gulf of Mexico is to abandon them in place after de-inventorying and preparing it for abandonment. If it is decided that removal of an abandoned pipeline is a desired option, plans must be made to access the pipeline by removing soil or rock cover if it is buried, remove pipeline anchors, recover crossing mats or perform sectional cutting of the pipeline in preparation for retrieval. Some of the common systems for protecting or anchoring pipelines for stability or to prevent unintended third party damage include:

- Trenching
- Burial
- Covering with aggregate or grout bags
- Mechanical anchoring.

The method used for exposing a pipeline prior to removal will depend on its accessibility, protection placed on the pipeline when installed, and local terrain.

If an abandoned pipeline is retrieved from the seabed, several options may be used including reverse lay barge or reel recovery, tow recovery or sectional recovery. In some cases a combination of these might be used as well, since some of the methodologies are dependant on the water depth and location of the pipeline. The recovery methods are discussed in detail below.

8.2 Pipeline Decommissioning

Prior to disposal of the pipelines, they will be purged and cleaned internally. The usual procedure is to use cleaning and separation pigs, propelled by suitable liquid, gas, gel or foam. If the propellant is to be left in the abandoned pipeline afterwards, it must be safe, non-corrosive and environmentally acceptable. The media that is commonly used is inhibited seawater.

Safe disposal of the remains of the final product in the pipeline is the first step in any decommissioning procedure. Of all the alternative methods of product disposal, it is preferable to use existing routes. Pipeline systems consist of flow lines, infield pipelines and trunk pipelines. In addition, a complex system may include one or more of the following: water injection, gas lift, chemical injection and hydraulic controls, and the associated equipment may be used for pumping and cleaning purposes during decommissioning. Product in the flow lines may be pumped out or reinjected into the reservoir.

All hydrocarbon products and the chemicals used to clean and purge the pipelines should be regarded as hazardous, and must therefore be considered as containing an element of risk to personnel and the environment.

The decommissioning procedure is assumed the same for all disposal options. Usually the pipeline is left in a “cold-phase” while disposal operations are prepared.

8.3 Leave in Place

Unless marine activities are affected the current practice, in the U.S. Gulf of Mexico and West Coast waters, is to abandon pipelines in place. Prior to abandonment, pipelines are purged of their contents, typically by pigging operations, and the residual contents properly

disposed. The pipeline is then filled with a suitable abandonment fluid. The media that is commonly used is inhibited seawater.
Fluids used in abandoned pipelines might typically be treated with an oxygen scavenger, a biocide, corrosion inhibitors, or other specific additives depending on the pipeline metallurgy, prior service and anticipated length of time of abandonment.

After the pipeline is filled with fluid, the ends are capped and typically jetted or buried beneath the seabed for protection.

8.4 Bury/Trenching

Burying or trenching involves covering the abandoned pipeline with soil or other suitable materials after it is abandoned. Burying or trenching methods would be the same as those used in installation of a new pipeline. Burying an abandoned pipeline might be performed to prevent future, undesired, third party damage that may primarily occur from commercial marine operations.

After years of operation some of the pipelines may already be covered with sand and gravel from local underwater currents.

8.5 Reverse Lay Recovery

Lay barges construct pipelines by assembling them on board from standard lengths of line pipe welded end to end. A standard length "joint" is approximately 40 feet long. The barge is propelled along the exact route of the pipeline by pulling on anchors or by using thrusters. As the barge moves forward, the welded pipeline is paid out the rear of the boat from a hinged ramp or stinger fixed to the side or stern of the vessel. (See figure A.1 in Appendix A).

Tensioners fixed to the assembly line ahead of the stinger hold the weight of the suspended pipeline. The suspended portion of the pipeline takes up an "S" bend configuration between the stinger and the seabed. This shape must be carefully controlled to avoid buckling distortion, and if the sea state exceeds certain limits, the pipeline may be abandoned temporarily over the end of the stinger to protect it from buckling. If a buckle does occur, the pipeline will have to be hauled back on board for repair, which may include dewatering if the buckle has allowed seawater into the pipeline.

With some additional steps, recovery of an abandoned pipeline may follow the same procedure as is used for recovering a buckled pipeline.

A procedure for the Reverse Lay Recovery method is included in Appendix B. This procedure is the basis for the risk analysis (SAFOP) documented in Appendix C.

8.6 Reverse Reel Barge Recovery

Depending on diameter, a reel barge can carry several thousand feet of pipeline. This enables appreciable lengths of pipe to be recovered quickly. The reel barge cannot lay or recover concrete coated pipe because the concrete coated pipe cannot be reeled onto the reel.
Pipeline recovery with a reel barge is the reverse of pipeline laying. The recovered pipe would be wound onto the reel (rather than being cut into sections as with the lay barge) for reuse or disposal onshore. Approximately the same size limitations would apply for reverse reeling operation as apply for reel laying operations. (See figure A.2 in Appendix A).

The reel ships/barges can recover pipe sizes up to 14" (pipe without concrete coating) without any modifications to existing reel ships/barges (Ref. /1/). High-grade steel pipe is less likely to be reeled due to lower bending capabilities.

A procedure for the Reverse Reel Barge Recovery method is included in Appendix B. This procedure is the basis for the risk analysis (SAFOP) documented in Appendix C.

8.7 Long Section Barge Recovery

In long section pipe recovery, the pipe is suspended from davits mounted on one side of a recovery vessel. While the vessel moves slowly along the route of the pipeline, the sling lengths are adjusted so that the pipe is lifted in a controlled "S" bend configuration to avoid buckling. The end of the pipe is fed through a cutting station near the bow of the vessel and the pipe cut into convenient lengths for shipping ashore in a supply boat. Long section barge recovery is suitable mainly for shallow waters. (See Figure A.3 in Appendix A).

A procedure for the Long Section Barge Recovery method is included in Appendix B. This procedure is the basis for the risk analysis (SAFOP) documented in Appendix C.

8.8 Tow Recovery

Davits are fitted to a recovery vessel in a similar way to long section barge recovery described above, except that the vessel carries tensioners and a stinger at both ends. The cutting station is mounted between the two ends of the vessel. (See Figure A.3 in Appendix A).

The pipeline is lifted onto the forward stinger and passed through to the aft stinger. Floatation buoys are attached, the pipe moved aft and the towing head picked up by a tug which pulls the buoyant pipeline away from the recovery vessel until the desired towing length, usually a few thousand feet is reached. The pipe is then severed on board the recovery vessel and the freed length of pipeline towed away for re-use or disposal.

The buoys are calculated to provide sufficient buoyancy for the pipeline to be towed on or close to the seabed, close to the surface or at a level midway between, depending on the sea state and condition of the seabed at the time of the operation.

A procedure for the Tow Recovery method is included in Appendix B. This procedure is the basis for the risk analysis (SAFOP) documented in Appendix C.

8.9 Short Section Recovery

The pipeline is cut into short lengths on the seabed using a submersible remote operated vehicle (ROV), robots, or divers. Cut lengths of pipe are lifted onto the recovery vessel by crane. Alternatively, the pipeline is lifted by davits and cut into single or double joints on the barge. The method is suitable for any size of pipeline, but is slow and requires high cost diving operations and subsea cutting equipment. (See Figure A.4, A.5 and A.6 in Appendix A).

A procedure for the Short Section Recovery method is included in Appendix B. This procedure is the basis for the risk analysis (SAFOP) documented in Appendix C.

8.10 J-Lift Recovery

The J-lay barge is designed primarily to lay the larger diameter pipelines in deep water. The tensioners and stinger are mounted on a nearly vertical tower extending down into the sea through a central moon pool in the vessel. This method avoids the excessive "S" bend stresses in pipelines that result from the pipeline's extra weight in very deep water. In other respects, J-lift recovery follows the same procedures as the other lay barge methods described above. (See Figure A.7 in Appendix A).

A procedure for the J-Lift Recovery method is included in Appendix B. This procedure is the basis for the risk analysis (SAFOP) documented in Appendix C.

8.11 Handling and Transport on Land

The following transport and handling operations on land have been identified as having potential adverse impacts on the safety:

- Unloading pipe lengths from the transport vessel and transferring to shore
- Transportation onshore
- Purging the pipe
- Removing anodes
- Removing concrete
- Removing protective coatings
- Cutting pipe
- Crushing concrete.

9. RISK ASSESSMENT

9.1 Introduction

From a safety point of view (occupational health & safety impact) activities involving a minimum hazard exposure to personnel are preferred. The risk assessment does not account for potential loss to equipment or assets.

The purpose of the safety evaluation is to determine if potential hazards associated with the disposal operations and activities can be adequately controlled.

The SAFOP technique (Safe Operations) was used for the risk assessment. The SAFOP was performed on February 18, 2004 with Tor Egil Nielsen from Scandpower as facilitator and Don Eckert and Glen Duhon from Global Solutions as experts on pipeline removal operations.

The review focused on personnel risk, however, a checklist usually applied for marine operations covering operational aspects and potential equipment damages was applied for the review. This was done to reveal operational problems that could lead to situations with increased risk to personnel. The checklist is presented below. The last five guidewords represent activities that can result in personnel injuries and they are included in the SAFOP sheets. In addition to the risks dealing with energy release and exposure to toxic substances, diving is historically a risky activity. The remaining applicable guidewords are discussed in general since they are assumed to be the same for all the different operations.

For each main removal activity, a short presentation of the main steps was given before execution of the SAFOP. The SAFOP was carried out for the pipeline disposal options listed in Chapter 5.

Operational review checklist

PREOP.CHECKS	:	Necessary equipment, tugs not available on schedule Necessary equipment checking/testing not performed
WEATHER	:	Unclear weather restrictions or unexpected deterioration of weather (abortion of operation). Weather forecasting, low temperatures
CURRENT	:	Problems related to strong, unexpected currents
POSITION	:	Object, grillage, tugs or vessel not in correct position
POWER	:	No power or insufficient power (tugs, electrical, hydraulic, air)
EQUIPMENT	:	Malfunction or lack of equipment

INSTRUMENTS	:	Malfunction or lack of instruments
RESPONSIBILITY	:	Undefined/unclear responsibilities (tugs, vessel, port)
COMMUNICATION	:	Malfunction or lack of communication equipment. Communication lines, noise, shift changes
EXECUTION	:	A work task is executed in a wrong way, timing, speed
PROCEDURES	:	Missing or unclear procedures
VISIBILITY	:	Can the operator(s) see sufficiently?
MOVEMENT	:	Objects, tugs or vessels move in an uncontrolled way
STABILITY	:	Unstable conditions
TOLERANCES	:	Tolerances for positioning, etc.
INTERFACES	:	Wrong, contamination, corrosion, marine growth, etc.
STUCK	:	Movement cannot be performed
RUPTURE	:	Rupture of critical equipment, overloading
ACCESS	:	Insufficient access/space on tugs, vessel, port
ESCAPE ROUTES	:	Sufficient, checked against requirements, protected
CONTINGENCY	:	Back-up procedures/equipment not available
OTHER	:	Other items not covered by the above guidewords
IMPACT	:	Impact between objects, squeezing (personnel)
DROP	:	Drop of objects from a higher level
FALL	:	Fall of personnel to lower level

ENERGY RELEASE	:	Electric, pressure, heat, cold, radioactive
TOXIC RELEASE	:	Release of hazardous substances

For the SAFOP review, each method for pipeline disposal was split into main activities (see Appendix B). For each of these main activities, the checklist above was applied. The results are given in the tables in Appendix C. The main findings are discussed in Chapter 9.2. It was assumed that all pipelines were flushed at the start of the operation.

Depending upon the nature of the findings in the hazard identification, the plan was to apply a fault tree analysis to illustrate the relationship between an undesired operations event and the causes of this event. No events suitable for a fault tree analysis were found during the hazard identification.

9.2 Hazard Identification

9.2.1 General

Shipping/Transport

The primary considerations to be evaluated for shipping/transport and other users of the sea are:

- Ability to meet all applicable rules and regulations
- Risk and physical impact
- Consequence for choice of routes.

Personnel Hazards

There are many hazards for personnel working on a pipe laying boat or barge and they vary according to factors including the boat or barge size, method of pipe retrieval operation and the number of personnel involved during a particular step in a pipe retrieval operation. Hazards to personnel could also include those associated with diving, if diving is required as part of the pipe retrieval method. Other hazards include being struck by moving equipment, pinched between equipment or pipe, falling from heights, hazards from welding operations and potential exposure to naturally occurring radioactive materials (NORM).

A typical boat or barge designed for pipe laying or retrieval operations vary in length depending on the size of the pipe the equipment on the vessel can handle. Boats and barges set up for pipe laying operations typically have a large flat deck covered with wood or some other slip resistant material. Pipe laying/retrieval vessels typically have either a large reeling spool for continuous reeling operations or multiple pipe racks or cages to lay or retrieve piping in sections.

Personnel hazards associated with pipe retrieval operations include the following:

- Being struck by moving equipment such as the pipe reel or joints of pipe rolling across the racks on the back of the vessel
- Being caught between moving joints of pipe or pipe racks being moved across the deck of the vessel
- Falling from a height of 4 or more feet from walkways or work platforms on the equipment
- Potential exposure to ultraviolet radiation from welding operations on the deck of the boat or barge during retrieval operations
- Potential exposure to NORM from pipe scale
- Potential exposure to any chemicals being used in a pipe retrieval operation.

If diving operations are involved in a pipe retrieval operation, hazards to divers are typical to those of other diving operations with the possible additional hazards of either under water torch cutting or use of hydraulic shears. Pipe retrieval operations involving the removal of pipe in sections may require the pipe be cut in sections under water, rather than on the boat deck, by use of a torch or hydraulic shears.

The frequency of accidents involved in pipe retrieval operations is difficult to determine since accident data does not differentiate between accidents from pipe retrieval operations from other offshore operations such as production, drilling, or other marine transportation operations. The number of accidents and accident potential is related to the time of personnel exposure during a given pipe retrieval operation. Therefore, if a pipeline is retrieved rather than being left in place, the exposure potential for personnel injuries is greater due to the increased exposure time of pipe retrieval operations on a boat or barge. The nature of the work can be compared with demolition activities. (See the comment related to "low status work" at the end of this section.)

Decommissioning

Activities involved in decommissioning of the pipelines are the same for all disposal options, therefore the risk for the decommissioning operations is not included in this report. All hydrocarbon products and the chemicals used to clean and purge the pipelines should be regarded as hazardous, and must therefore be considered as containing an element of risk to personnel and the environment. The activities are standard operations including flushing, pigging as performed during normal operations on the installation. The cutting of the turn tube etc. is assessed in the different disposal options and recovery methods.

Structural Integrity

Integrity of the pipes after several years of operation can be poor. Very often a 20-year design life is reflected in the corrosion protection design (corrosion allowances, sizing of anodes, etc). Older pipelines can be severely corroded and beyond a condition where some of the recovery methods are possible or may result in increased risk to personnel during recovery operations. Inspection of the structural integrity for the pipeline prior to removal might be difficult or extremely expensive.

Communication

Communications are critical during all pipeline disposal operations. Communication details and useful phone numbers need to be established and dedicated radio channels must be reserved for the offshore operations.

Communication lines have to be checked before starting operations. Operations must be stopped if there is significant deterioration, or complete loss of communication lines, until they are restored.

Communication procedures also must be established for communication with neighboring fixed installations, involved vessels, merchant and operating vessels in the area, and shore.

ROV video has to be displayed on the vessel bridge. Operations have to be halted if the ROV is critical to recovery activities and the display deteriorates or is lost. .

Weather

The operating vessels will have weather limits for station keeping. The limits and the criteria will be different for the different recovery phases. The weather limitation for initiation of operation shall consider combinations of current, wind and waves. Usually these figures shall be related to a worst-case scenario for the area.

At least two independent, high quality weather forecasts shall be required. The weather forecasts shall be compared and if necessary the forecaster will be contacted for further clarifications prior to making decisions with respect to the start of the pipeline initiation operation.

Procedures must be established for halted activities due to adverse weather conditions and/or emergency situations.

Preparation Works

The survey/support vessel shall perform a pre recovery survey and debris removal from the pipeline.

The ROV on the survey/support vessel shall carry out a detailed video and obstacle avoidance survey of the route corridor. If any objects are found that could be hazardous to pipe recovery, the ROV operators will remove it outside the corridor using its manipulators or if the ROV is incapable of moving the object it will be reported to the recovery barge.

Objects considered to be hazardous are large boulders, hard debris with sharp edges and any other objects that could damage the pipe and cause rupture.

Equipment Failure

Equipment failures affecting the recovery activities fall into three different categories as listed below:

- Vessel navigation and propulsion
- Pipeline handling systems
- ROV failure.

Vessel Navigation and Propulsion

The different recovery vessels have different positioning systems; however, most are DP (Dynamic Positioning) operated. Some vessels have two independent DP systems. If the DP system develops a fault, the pipe recovery has to be stopped and the vessel has to maintain position using taut wire system and/or vessel acoustic transponder.

Pipeline Handling System

If the main systems fail, recovery must be stopped and repairs carried out while the vessel maintains its position. However, some of the typical systems have redundancy and it may be possible, depending on the nature of the failure, to continue operations with a reduced capacity after an inspection of the equipment.

ROV Failure

If the ROV fails during lift off monitoring, at crossings or within 500 meter zones of installations that are in production/operation the operation will be stopped and the vessel will go on mechanical breakdown until the ROV monitoring is resumed.

Operations within the 500-meter Zone

Some of the recovery operations might be carried out while installations are in production/operation. This has to be planned in accordance with the installations specific safety zone procedures. No hot work will be permitted without Hot Work Permits from the installation.

Launch and recovery of ROV systems are critical due to waves and breaking through the water surface. Documents applicable for the work (work permits etc.) shall be in place prior to commencing the work.

Low Status Work

Decommissioning is often considered low status work compared to installation and construction. This is often seen on land based construction/demolition work as well. Often the work is performed with the same personnel that operate the vessels during pipe lay operations. The lack of status of the operation may result in reduced focus on the operation and could cause major safety issues.

9.2.2 Leave in Place

Due to the limited number of man-hours compared to the trenching/recovery options, the risks associated with the Leave in Place option are limited. Basically, the cutting and preparation of the pipeline ends will be the only short-term risk contributor.

In the long term, abandoned pipelines may result in risks for merchant vessels operating in the U.S. waters. After the pipelines start deteriorate, they might be spread over a larger area, and therefore might cause problems especially for fishing vessels. These risks will mainly be to material assets.

For some of the abandoned pipelines in the North Sea and the U.S. water, it has been decided to leave them filled with seawater instead of corrosion inhibitors to enhance the corrosion and deterioration process.

A SAFOP analysis for the Leave in Place option was conducted, and the SAFOP sheets can be found in Appendix C.

9.2.3 Bury/Trenching

Some subsea pipelines were buried when they were laid or have been covered by a shifting seabed. The risk associated with this disposal method will mainly be the same as for the Leave in Place option, since the trenching operations will be remotely operated by use of ROV, ploughs, jetting sleds etc.

The remotely operated activities included in the bury/trenching activities are simple and involve a limited number of personnel on the vessel.

A SAFOP analysis for the Bury/Trenching option was conducted, and the SAFOP sheets can be found in Appendix C.

9.2.4 Reverse Lay Recovery

Integrity of the pipes after several years of operation can be questionable. Very often a 20-year design life is reflected in the corrosion protection design (corrosion allowances, sizing of anodes, etc) and therefore the pipelines may remain in near-mint condition. However, if older pipelines were insufficiently maintained and/or had not been retrofitted, they can be severely corroded and beyond a condition where a reversed lay recovery method is possible.

The option involves a limited number of subsea activities, but a higher amount of man-hours on the barge. Efforts should be taken to plan the on barge activities at a safe distance for personnel not involved in recovery operations to limit the number of people exposed to the hazards.

A SAFOP analysis for Reverse Lay Recovery option was conducted, and the SAFOP sheets can be found in Appendix C.

9.2.5 Reverse Reel Barge Recovery

The main hazard in the reversed reel lay method is linked to a rupture of the pipe due to structural weaknesses. This can cause the pipe to fly up, spin out of control and strike personnel close by. When being unwound on land, before being cut in shorter lengths, residual stresses in the pipe can result in the ends unexpectedly striking out and hitting personnel. Integrity of the pipes after several years of operation can be questionable. Very often a 20-year design life is reflected in the corrosion protection design (corrosion allowances, sizing of anodes, etc) and therefore the pipelines may remain in near-mint condition. However, if older pipelines were insufficiently maintained and/or had not been retrofitted, they can be severely corroded and beyond a condition where a reversed lay recovery method is possible or may result in increased risk to personnel during recovery operations. Inspection of the structural integrity for the pipeline prior to reel recovery might be difficult or extremely expensive.

A SAFOP analysis for the Reverse Reel Barge Recovery option was conducted, and the SAFOP sheets can be found in Appendix C.

9.2.6 Long Section Barge Recovery

An accident while pipe and equipment are being lifted to the surface in the vicinity of operating installations could cause damage to subsea equipment, which may result in an oil and gas release. A release may result in personnel injuries, harm to the environment and equipment damage. When pipes are being stowed on board the vessel, pipes rolling on deck can injure personnel. Sea fastening of equipment will be required during Long Section Barge Recovery operations.

A SAFOP analysis for the Long Section Barge Recovery option was conducted, and the SAFOP sheets can be found in Appendix C.

9.2.7 Tow Recovery

An accident while pipe and equipment are being lifted to the surface in the vicinity of operating installations could cause damage to subsea equipment, which may result in an oil and gas release. A release may result in personnel injuries, harm to the environment and equipment damage. When pipes are being stowed on board the vessel, pipes rolling on deck can injure personnel. Sea fastening of equipment will be required during Tow Recovery operations.

If the pipe under tow fills with water, there is a risk it will sink. The risks of this happening are greater during removal operations than during installation because of the potential deteriorated condition of the pipe. To avoid accidents that can lead to spills of oil or gas, towing should not be done in the vicinity of operating oil and gas installations.

The Tow Recovery involves a high number of diving operations. In rough weather, divers can sustain impacts while going through the splash zone. In rough water, excessive surge can cause unexpected movements of objects being lowered to the diver, which can result in impacts. High currents can also slam the diver into the subsea structures. Divers are at risk of falling objects while the barge deck crane is utilized to move equipment and materials in preparation for Tow Recovery. If the pipeline is under tension, it can swing out and hit the diver when it is cut.

A SAFOP analysis for the Tow Recovery option was conducted, and the SAFOP sheets can be found in Appendix C.

9.2.8 Short Section Recovery

An accident while pipe and equipment are being lifted to the surface in the vicinity of operating installations could cause damage to subsea equipment, which may result in an oil and gas release. A release may result in personnel injuries, harm to the environment and equipment damage. When pipes are being stowed on board the vessel, pipes rolling on deck can injure personnel. Sea fastening of equipment will be required during Short Section Recovery operations.

The Short Section Recovery involves a high number of diving operations. In rough weather, divers can sustain impacts while going through the splash zone. In rough water, excessive surge can cause unexpected movements of objects being lowered to the diver, which can result in impacts. High currents can also slam the diver into the subsea structures. Divers are at risk of falling objects while the barge deck crane is utilized to move equipment and materials in preparation for cutting and lifting of pipes. If the pipeline is under tension, it can swing out and hit the diver when it is cut.

The Short Section Recovery is a time consuming operation, which means the number of man-hours required, and therefore the risk, will increase.

A SAFOP analysis for the Short Section Recovery option was conducted, and the SAFOP sheets can be found in Appendix C.

9.2.9 J-Lift Recovery

Review of reversed J-curve procedures shows that that their working environment consequences correspond to those identified for reversed S-curve procedures, that is, cutting, moving, lifting and stowing pipe.

A SAFOP analysis for the J-Lift Recovery option was conducted, and the SAFOP sheets can be found in Appendix C.

9.2.10 Handling and Transport Onshore

General

For the duration of the onshore cleaning and/or demolition, necessary consents and authorizations have to be obtained. The onshore facilities performing the work need the appropriate permits in place, or pending, to deal with the various waste streams (including radioactive materials) arising from the demolition activity.

Material Tracking

Throughout the demolition period, a detailed tracking and quantitative accounting system will be maintained for the handling, transportation and disposal of:

- All hazardous and non-hazardous materials
- Equipment wastes
- Other products.

The final tracking report will identify all net quantities added to or exported from the work site during demolition.

Work Site Clean Up

The work site must be demobilized and cleaned to the requirements set forth in any approvals, consents or permissions granted at the commencement of the work. The entire work site has to be cleaned to ensure that no environmental hazards remain after the demolition. One way of doing this is to perform an environmental audit to verify cleanliness of the site.

Hazard Management

Hazard Management is a key element of the planning and implementation process for pipeline decommissioning. This will ensure hazards are identified and risks assessed so work systems can be implemented prior to decommissioning activities being undertaken. Various techniques can be used, e.g. HAZID, SAFOP, HAZOP, safety reviews, specific training, etc. to ensure that risk to personnel and the environment can be avoided or controlled. Assessments will typically be carried out for activities that involve:

- Lifting of heavy pipe sections
- Working at height
- Work in a confined area
- Work in gaseous atmosphere
- Handling and disposal of hazardous materials
- Removal and disposal of LSA materials
- Electrical hazards.

In general, demolition of pipelines is a simple job compared to demolition of a jacket or topside. The activities should be performed remotely to prevent personnel from being directly involved in the activities. The job will consist of few, non-complicated operations, and machines today perform most onshore demolition.

Unloading Pipe Lengths from the Transport Vessel and Transferring to Shore

Unloading and stowing pipe are, on the whole, proven procedures. But, there may be an added risk of work accidents when unloading and using a crane because pipes may be deteriorating, or parts of the concrete coating may drop off. Whole pipe lengths can slip and fall because the pipe clamps are not designed to lift pipe coated with concrete at both ends.

Transport Onshore

The number of pipelines that have been recovered is limited. Most of the out-of-service pipelines have been left in place. The only pipelines that have been removed are when they cause problems for new pipelines crossing the same area. Therefore, the number of pipeline recovery sites in the U.S. is limited. Due to different recycling and waste management regulations in the different states, the pipelines might have to be transported to a selected state for recycling. Decommissioning in other parts of the world shows that as soon as removal of pipelines becomes a common practice, pipeline demolition sites will be established at the coastline for easy access for ships, and removal barges. Based on this it is assumed that the land transportation of the pipelines will be limited. Transportation of “isolated” material such as steel and concrete may occur since recycle facilities/mills might be present far from the demolition sites.

Land transportation can involve activities by both train and road. These activities are common practice today, and the risk involved is assumed to be limited.

Purging the Pipe

Even if pipelines and cables have been purged at sea, it is likely that some of them will need more cleaning when on land because they may still contain production residues, including some containing heightened concentrations of LRA (low radioactive) scale. It is especially considered hazardous to health to inhale pulverized LRA scale during the removal of such deposits.

There is little risk of radiation when working with LRA scale, but everybody who takes part in any work entailing direct contract with it must be given a thorough briefing on the risk and means of protection.

All hydrocarbon products and the chemicals used to clean and purge the pipelines should be regarded as hazardous, and must therefore be considered as containing an element of risk to personnel and the environment.

Removing Anodes

By the time pipelines are lifted and removed from the sea, most anode material will have eroded and the steel structure, its protective coating, insulation if any and its concrete coating remain. If a "hot pass" is used to cut off the anodes, it can liberate gas from the anode material, the pipe steel and what is left of the corrosion resistant coating.

Removing Concrete

There is three recognized ways to remove the concrete coating: by explosives, by gouging or chipping and by pressing out the pipe. None of these methods is an industrial process, while all of them have traits of work-intensive heavy labor with person-injury risks.

Removal by using explosives runs the risk of causing injury as a result of careless use and storage. Gouging can create great clouds of dust, which can be harmful for the working crew. In order to press out a steel pipe, its protective coating has to be heated. This releases gases that are hazardous from the working environment point of view.

Removing the Protective Coating

There are several methods for removing the protective coating, but none of them is very suitable for large-scale removal, nor have any of them yet been used on whole pipe sections.

There are many kinds of corrosion resistant coatings in use on pipelines. Some coating components are strong allergens and carry a high risk of causing eczema. The further use of some current components has been prohibited, because of the health risk and other reasons.

Depending on the coating and the removal method, removing a protective coating can bring about the release of hazardous gases. The work crew can also be exposed to dust that can precipitate asthma and other allergic reactions or irritate the skin. In some cases they may be glass fiber or asbestos dust from protective layer reinforcement.

Cutting Pipe

In cutting there is a risk of injury from rotating machinery. The operator can also be exposed to concrete and protective coating dust, which in some cases contains remnants of glass fiber and asbestos, as well as to toxic/radioactive substances and hydrocarbon residues.

Cutting Concrete

Concrete is crushed before being transported to a reception facility for recycling or deposit. Crushing produces dust and noise, and the dust from crushed concrete will have the same affect on worker health as dust from the removal of the concrete coating.

10. COST ESTIMATES

Costs have been computed on the basis of using existing equipment and methods for the production, installation and operation of pipelines. The pipeline recovery company Global Industries has assisted in these estimates. Removal of the pipelines specified in Chapter 7 costs the most, about $16.2 billion including handling and deposit on land. The cost does not include transport onshore and any further processing or landfill cost. Burial/ trenching is estimated at $1.6 billion. In principle, leaving pipelines in place after flushing has virtually no cost.

The average cost per mile is calculated from the 200-500 ft water depth for all the different pipeline diameters. This depth is used because most of the pipelines are found in these water depths. It is assumed that the pipelines are 4 miles long or longer since this is the minimum length needed to be able to apply most of the removal techniques (few pipelines are shorter than this). Reverse Lay is chosen as the removal method because currently this is the most used method for both pipeline lay and removal, therefore detailed cost data are available.

From an economic point of view minimizing the costs associated with decommissioning will be attempted. This does not mean the current lowest possible disposal cost is used, but rather the lowest possible disposal cost in a long-term perspective.

Coarse cost estimates have been established for the different alternatives where appropriate. This is partly based on a qualitative assessment. A more thorough economic evaluation with NPVs of the established scenarios, both from a private company point of view and from a society point of view, should be considered.

10.1 Leave as is

This alternative, in principle, has virtually no cost, but other sea users would likely want some control over the state of the abandoned pipelines. Such cost has not been considered. Costs related to cutting the pipe from the platform and dumping rocks on the pipe ends, if necessary, have not been considered either.

10.2 Burial/Trenching

The calculations are based on the use of the same method as is used to cover over new pipelines. The estimate is for pipelines and cables to be covered in their full, reported length to a depth of 0.5 m.

All together there is approximately 33,291 miles of pipelines in the U.S. waters. In this study it is assumed that the cost for burial/trenching will be the same for all different pipe diameters. A trenching price of $50,000 per mile, Ref. /2/, of pipe gives a total cost for burial/ trenching of $1.6 billion. Pipeline crossings or other conditions that would complicate the work have not been taken into account. The calculations are based on the presumption that trenching is possible.

10.3 Removal

The removal of pipelines is based on the use of current installation equipment and is therefore not optimized. Experience of pipeline removal in the U.S. waters is limited to a few incidents. If it should be necessary to remove a greater amount of pipelines in the future, experience would be acquired and in all probability a market for better methods and technology would evolve. The development of new technology for quicker removal could cut costs by half.

Pipeline removal costs vary according to many factors. Some of these factors include:

- Location of the pipeline
- Diameter of the pipeline
- Depth of the pipeline
- Length of the pipeline
- Coatings on the pipeline
- Number of crossings the pipeline has with other pipelines
- Availability of barges that can perform the task of pipeline removal.

The location of the pipeline has an effect on the cost of its removal. Pipelines located in the Gulf of Mexico cost less to remove than those located off the west coast or in Alaska waters because most pipe handling vessels are based in the Gulf of Mexico. If these vessels have to work in west coast waters or Alaskan waters, the mobilization time is increased substantially because the vessels must travel through the Panama Canal and onto the west coast or to Alaska. If the vessels are too large to travel through the Panama Canal, they must sail around the coast of Africa. This extra mobilization time is typically one week or more and can add up to 35 million in mobilization expense depending on the size of the vessel.

The diameter, depth and length of the pipeline being removed have a direct effect on the costs. Larger diameter (30"-36") pipelines may cost 2 to 2.5 times the cost of removing smaller (less than 4") pipelines. The depth of a pipeline will typically have cost consequences for retrieval. For example, pipelines to be retrieved may cost up to 50 % more when the water depth increases from 200 feet to 750+ feet. The length of the pipeline will also affect the cost of retrieval. For example, retrieving a pipeline that is one mile in length will have the same mobilization costs as retrieving a pipeline that is several miles long. The mobilization costs must be spread out on a per/mile basis for a pipeline to be retrieved. Obviously longer pipelines will have a lower cost/mile for mobilization costs.

If a pipeline has coatings on it, these coatings add to the cost and complexity for retrieval. Coatings also add to the cost of disposal for piping because the coatings add additional weight to the piping and may result in additional retrieval cost if the coatings have to be stripped in places where the piping is to be cut for retrieval.

If a pipeline has numerous crossings with other pipelines, the cost for retrieval may be increased. Typically, a pipeline would be cut and its ends buried some distance from a crossing with another pipeline. If a short pipeline segment cannot be left in place where it crosses under another pipeline, then the pipeline being crossed under must be lifted to facilitate the removal of the pipeline segment. This will add cost and complexity to pipeline removal because the pipeline being crossed must be moved and potentially may have to be shut in and de-pressurized prior to moving.

The cost estimates for pipe removal in the Gulf of Mexico are based on the following assumptions:

- Pipeline length 20,000 feet
- Pipelines are flushed clean of contaminants
- The salvage vessel is within a 2-day mobilization radius
- The "Reverse Lay Recovery" recovery method is used as the basis for the estimates.

The pipe disposal cost includes loading the pipe sections onshore from the barge, cutting in 40 feet lengths and loading onto other means of transport such as a barge or a truck. The disposal cost does not include onshore transport or any further processing of the pipe sections or cost in connection with landfills.

Table 10.1 to 10.6 gives the estimates for the removal and disposal of different sized pipelines for different water depth. The data also includes onshore demolition of pipes with coating.

Table 10.1: Cost Data for Pipeline Diameters < 4"

	< 4" P/L diameter	Pipe length (ft)	Cost ($/mile)	Vessel working rate/day	Cost/day for retrieval	Pipe disposal cost/mile
Water depth	0-200 ft	20,000	208,000-320,000	93,000-160,000	227,000-332,000	52,800
Water depth	201-500 ft	20,000	238,000-350,000	106,000-178,000	247,000-345,000	52,800
Water depth	500 + ft	20,000	375,000+	188,000+	351,000+	52,800

Table 10.2: Cost Data for Pipeline Diameters 4" - 12"

	4"-12" P/L diameter	Pipe length (ft)	Cost ($/mile)	Vessel working rate/day	Cost/day for retrieval	Pipe disposal cost/mile
Water depth	0-200 ft	20,000	238,000-394,000	106,000-182,000	274,000-341,000	79,200
Water depth	201-500 ft	20,000	320,000-433,000	160,000-200,000	332,000-356,000	79,200
Water depth	500 + ft	20,000	375,000+	188,000+	351,000+	79,200

Table 10.3: Cost Data for Pipeline Diameters 12" - 16"

	12"-16" P/L diameter	Pipe length (ft)	Cost ($/mile)	Vessel working rate/day	Cost/day for retrieval	Pipe disposal cost/mile
Water depth	0-200 ft	20,000	262,000-422,000	132,000-182,000	290,000-305,000	84,000
Water depth	201-500 ft	20,000	380,000-490,000	170,000-200,000	326,000-349,000	84,000
Water depth	500 + ft	20,000	412,000+	192,000+	330,000+	84,000

Table 10.4: Cost Data for Pipeline Diameters 16" - 24"

	16"-24" P/L diameter	Pipe length (ft)	Cost ($/mile)	Vessel working rate/day	Cost/day for retrieval	Pipe disposal cost/mile
Water depth	0-200 ft	20,000	371,000-459,000	171,000-186,000	308,000-315,000	95,000
Water depth	201-500 ft	20,000	413,000-509,000	183,000-205,000	312,000-313,000	95,000
Water depth	500 + ft	20,000	456,000+	202,000+	308,000+	95,000

Table 10.5: Cost Data for Pipeline Diameters 24" - 30"

	24"-30" P/L diameter	Pipe length (ft)	Cost ($/mile)	Vessel working rate/day	Cost/day for retrieval	Pipe disposal cost/mile
Water depth	0-200 ft	20,000	412,000-556,000	174,000-188,000	288,000-300,000	105,600
Water depth	201-500 ft	20,000	459,000-620,000	186,000-207,000	305,000-317,000	105,600
Water depth	500 + ft	20,000	509,000-	205,000+	315,000+	105,600

Table 10.6: Cost Data for Pipeline Diameters 30" - 36"

	30"-36" P/L diameter	Pipe length (ft)	Cost ($/mile)	Vessel working rate/day	Cost/day for retrieval	Pipe disposal cost/mile
Water depth	0-200 ft	20,000	494,000-639,000	174,000-191,000	269,000-276,000	116,200
Water depth	201-500 ft	20,000	556,000-717,000	188,000-210,000	288,000-294,000	116,200
Water depth	500 + ft	20,000	620,000+	207,000+	305,000+	116,200

According to MMS data, the majority of pipelines (98+ %) are in the Gulf of Mexico waters.

Based on the information above, the cost estimates for the three different areas of concern are calculated. The average cost per mile is calculated from the 200-500 ft water depth for all the different pipeline diameters. The costs for the Gulf of Mexico include mobilization. For West Coast waters and Alaskan waters mobilization costs are not included. This is discussed earlier in this chapter.

Table 10.7: Cost Data for Pipelines in the Gulf of Mexico

Pipe diameter	Pipe length (miles)	Avg. cost ($/mile)	Disposal cost ($/mile)	Sum ($ billion)
< 4"	2,683	294,000	53,000	0.9
4"-12"	20,002	377,000	79,000	9.1
14"-16"	2,874	435,000	84,000	1.5
18"-24"	4,612	461,000	95,000	2.5
26"-30"	1,674	540,000	106,000	1.1
> 30	1,055	636,000	116,000	0.8
Sum				**16.0**

Table 10.8: Cost Data for Pipelines in the West Coast Waters (not Including Mobilization)

Pipe diameter	Pipe length (miles)	Avg. cost ($/mile)	Disposal cost ($/mile)	Sum ($ billion)
4"-12"	61	377,000	79,000	0.027
14"-16"	108	435,000	84,000	0.056
18"-24"	52	461,000	95,000	0.029
26"-30"	10	540,000	106,000	0.006
Sum				**0.12**

Table 10.9: Cost Data for Pipelines in the Alaskan Waters (not Including Mobilization)

Pipe diameter	Pipe length (miles)	Avg. cost ($/mile)	Disposal cost ($/mile)	Sum ($ billion)
4"-12"	150	377,000	79,000	0.07
16"-24"	10	461,000	95,000	0.006
Sum				**0.076**

If all of the pipelines currently in service were to be removed after abandonment, the costs associated with this removal would be many times that of leaving the pipelines in place. Using the cost estimates and pipeline lengths estimated above, the approximate cost of removing and disposing all pipelines currently in service would be $16.2 billion dollars, assuming an average depth in the 200-500 foot range and each portion of pipeline being approximately 4 miles long. The cost does not include transport onshore and any further processing or landfill cost.

10.4 Recycling and/or Deposit Onshore

Many component parts of pipelines and cables can be recycled, and some components can be incinerated for energy recovery. However, high costs are associated with removing and separating out components for recycling from the bulk of material where there is a high ratio of low value components like concrete and asphalt coating. Materials with a recycling potential are copper, lead, aluminum, plastic/rubber and duplex steel. The economic benefit of recycling is minimal, except for steel.

The alternative to re-use or recycling the pipeline materials is disposal in municipal land-fills. Any hazardous material recovered will need to be sent to a hazardous waste disposal site for destruction.

11. ENVIRONMENTAL ASSESSMENTS

11.1 General

When considering the environmental impacts with regards to disposal of decommissioned pipelines, both the short and the long-term impact on environment must be considered. These assessments will be based on a qualitative assessment of the following factors:

- Energy (consumptions and total energy impact)
- Emissions to atmosphere
- Discharges to sea or ground
- Physical impacts/effects on habitat
- Aesthetic impacts
- Waste/resource utilization
- Littering.

As a part of the qualitative assessments, the possible impacts and mitigating actions that could avert negative effects and promote positive benefits will be discussed. The impact that pipeline removals have upon scrap yards and the highway and rail systems will also be addressed.

In reviewing the environmental perspective, the ideal option *appears* to be that of leaving the area the way it was before the oil industry arrived. This would mean all pipelines would be removed. However, the best option for the environment when considering efficient use of resources will be to reuse as much equipment as possible. Reuse within the oil industry is optimal because it requires less modification. Reuse for other purposes may also be beneficial simply because new resources will not be depleted.

If pipelines absolutely cannot be reused, then removal and recycling will be prioritized over removal and disposal due to the long-term environmental benefits of recycling. Likewise, abandonment will be thoroughly reviewed and considered if it is found to benefit marine life and habitat, or if removal is impossible or represents an unacceptable risk or impact to the environment.

In general there is an area no more than 300 ft wide on either side of a pipeline that can likely be impacted regardless of the disposal option, and any impacts will on the whole be insignificant. Rock dumping on pipes left in place can bring about local changes of bottom topography.

The area's sediment type, the way the pipeline is laid, and what disposal alternative is chosen determine local consequences for bottom habitat. The impacts are limited to local disturbances in a narrow belt following the pipeline route and for as long as it takes the disturbed habitat to adjust to the changed environment and reconstitute itself.

Energy (Consumptions and Total Energy Impact)

Energy issues are considered important factors in evaluation of the environmental impacts of disposal of redundant pipelines. There are various ways of accounting for energy effects, and a wide range in the input data that is used. Two factors predominate when assessing the alternative disposal options:

1. Actual direct consumption of energy (fuel and electricity) for vessel operations and for melting down materials. This is defined as Energy Consumption in this report
2. Theoretical energy consumption for virgin production of materials in amounts corresponding to those not being recycled (represents potential energy savings by recycling). This is defined as Total Energy Impact in this report.

The pipelines are constructed mainly of steel with different types of coating. The actual cutting operations offshore have little impact since they use little fuel or electricity. The key factors in the energy analysis are thus the quantity of steel in the installations and the activities of the marine vessels involved in the removal process.

Emissions to Atmosphere

For the emissions assessments, the focus of atmospheric emissions is both on actual emissions as well as emissions associated with replacement of materials. The emission component CO_2, NO_X and SO_2 were assessed. The harmful effects can be summarized as follows:

Emission component:	*Harmful effect:*
CO_2 (Carbon dioxide)	Increases greenhouse effect
NO_X (Nitrogen oxides)	Causes respiratory complaints
SO_2 (Sulfur dioxide)	Heightens risk of respiratory complaints in conjunction with other components. Acidifies soil and watercourses.

As described above, CO_2 is a global ecological problem and the exact location of the release is not of great significance. For nitrogen oxides, NO_X, and sulfur oxides, SO_2, the effects are regional and local in nature. Not withstanding this, no assessment has been made of their effects on the local environment due to the uncertainty regarding where the disposal will take place.

Discharges to Sea or Ground

The focus is on

- type and amount of discharge
- time and duration
- location of discharge
- presence of natural resources, if any
- effects on natural resources.

Since the exact location for the operations are unknown, general assessments are made. It is worth noting that most of the pipeline disposal options involve minimal discharges into the sea, water or ground.

Physical Impacts/Effects on Habitat

This topic is included to cover any potential impacts that are largely physical in nature, for instance removing gravel from the seabed to get access to the pipelines.

Colonies of benthic organisms are vulnerable to impacts from dumping, dredging, cuttings piles, frequent trawling, loss of oxygen to algae blooms, and input of organic compounds and other sources. But, because most species have short reproduction cycles, stocks are capable of rapid re-growth once the source of pollution is eliminated. The longer-lived species need more time to regain their normal abundance, and even though an impact may have little effect, the natural species composition of the ecosystem is most likely adversely affected.

Aesthetic Impacts

This topic covers issues largely related to health and the local environment (noise, dust, odors). Where relevant, assessments are also made of any “visual pollution”.

Waste/Resource Utilization

Sound utilization of resources, with re-use and recycling as the most favorable options, is the starting point for this topic. Therefore, this assessment makes a scientific evaluation of the materials, and to quantify volumes of substances that need to be disposed of as waste.

Littering

"Littering" in this assessment, relates to the sea, since waste taken to land will be handled in accordance with detailed regulations aimed to prevent littering. "Littering" in this report is therefore defined as leaving things in the sea that were not originally present. In a long-term perspective, the litter topic is considered to be among the most important environmental issues. In cases where litter is deemed to have the potential to constitute a problem, this is emphasized.

11.2 Leave in Situ

Energy and Emissions

The leave in situ (in place) option has minor use of energy and minor emissions. Energy consumption and emissions from vessels performing rock dumping, burial, surveying and removal of possible pipe gives quite modest numbers.

Even when considering theoretical "replacement emissions" the leave in place option has the lowest emissions for all type of gasses (Ref. /3/).

Discharges to Sea or Ground

Mercury and cadmium, metals in pipelines and anodes, are believed to have a potential for a negative impact the environment. However, estimated losses of mercury and cadmium from pipelines are responsible for only a small percentage of the total annual anthropogenic releases in the U.S. waters. The mercury from pipelines comes from aluminum anodes that may be in use along some of the pipelines installed before 1980 (Ref. /3/).

Of the organic compounds total hydrocarbons (THC) and poly aromatic hydrocarbons (PAH) are seen as the most hazardous. THC inputs from pipelines will be insignificant and are not considered to have a noticeable effect on the marine environment. The main source of PAH is the corrosion-protective layer made of asphalt or coal tar. Since PAH is water soluble only to a minor degree, it will be a major environmental hazard only when organisms feed on particulate material.

Environmental issues studied include possible discharges or leaching of preservation fluid and structural materials to sea in the short and long term period. The biocides used for preservation of some re-usable lines are easily degradable in the marine environment. The effect is thus considered of low importance. The probability for leaching is also very low.

The structural materials in the pipelines are considered inert to the environment. Metals in anodes theoretically represent a certain potential for environmental effects, however, the metals leach slowly giving low concentrations in seawater/pore water. Normally, the metals will rapidly form complexes or salts with other components of the water; therefore, no acute toxicity to organisms is foreseen.

Physical Impacts/Effects on Habitat

Exposed pipeline ends at platform locations and buckled pipeline sections can be a problem for the fishing industry once trawling activities resume. Three alternative methods can be used to alleviate problems associated with exposed pipeline ends and buckled pipeline sections; rock dumping, further burial, and removal. Rock dumping is the least favorable to the fishing industry of the three alternatives. However, rock dumping has already been performed at several ends and some stretches of pipeline, so further rock dumping will not create a new problem for the fishing industry.

Disintegration of the pipelines will start with the anodes. The consumption rate of anodes is calculated, giving a remaining lifetime for anodes in the range of 40 - 350 years with the majority in the range of 40 - 80 years. There is a great uncertainty with the exact time frame for disintegration. This will also be dependent on whether the pipelines are buried or not.

Effects on the seabed habitat and substrata due to rock dumping is found to be very local and of minor importance. It is limited to 100-300m from the installations, where rock dumping often is present.

Aesthetic Impacts

No aesthetic impacts are found since all involved operations will be offshore.

Waste/Resource

Leaving pipelines in place has a negative impact when it comes to the resource issue. The pipelines represent a significant amount of steel, which cannot be used for recycling the pipelines are not recovered. This means all materials in pipelines will be disposed of as waste.

Littering

Littering effects by spreading of fractured pipe is considered negligible.

Altogether the impacts on the environment and the marine environment of pipelines and cables left in place are found to be very minor.

11.3 Bury/Trenching

Energy Consumption and Emissions

The bury/trenching option has some use of energy and some emissions from use of vessels for jet sled operations or rock/gravel dumping. However, the energy consumption and the emissions are considered minor compared to the pipeline recovery options. Only one vessel will be involved for each section of pipeline and it will only be used for a limited number of days.

Discharges to Sea or Ground

The discharges to sea are considered the same as for the Leave in place option. The only difference will be the long-term effects. Since the pipelines are not in direct contact with the water, the disintegration and discharge process will be delayed, and or spread over time. This means the environmental impact from discharges will be less than for the leave in place option.

Physical Impacts/Effects on Habitat

If a pipeline is to be left in place after safeguarding by trenching, burial, rock dumping or other means of cover, these measures can impact habitats locally along the pipeline route, but the area disturbed is very small.

It is assumed that the bury/trenching option will leave no pipeline ends open in the sea.

Effects on the seabed habitat and substrata due to rock dumping is found to be very local and of minor importance.

Aesthetic Impacts

No aesthetic impacts are found since all involved operations will be offshore.

Waste/Resource

Leaving pipelines in place has a negative impact when it comes to the resource issue. The pipelines represent a significant amount of steel, which cannot be used for recycling the pipelines are not recovered. This means all materials in pipelines will be disposed of as waste.

Littering

Littering effects caused by spreading of fractured pipe is considered negligible.

There will be minimal impact from pipelines that were trenched and naturally covered. Observations indicate that pipelines on sand bottoms will be wholly covered or buried within 10-15 years after being laid (Ref. /2/).

Altogether the impacts on the environment and the marine environment of pipelines buried or trenched are found to be very minor.

11.4 Pipeline Removal

The differences in environmental impacts between the different removal options are small; therefore the removal options are assessed as one. When differences are discovered, this is specified in the text.

Energy Consumption and Emissions

Removal of pipelines demands extensive marine operations over a long period. From an energy standpoint, the recycling of the pipeline materials will not compensate for the energy consumption of the recovery vessel operations. Compared with the leaving in place option, removal demands 70 % more energy (Ref. /3/).

As in the case of the energy, the emissions to atmosphere are significantly higher for the removal options than the leave in place option. CO_2 emissions are about 120 times higher for removal than for leaving in place (Ref. /3/).

If pipelines are to be removed, the lowest aggregate level of emissions and least waste will be realized by re-use of the pipe or steel recycling. This is compared to disposing of the pipe in a landfill and new pipe production. However, NO_x and dust emissions from the recycling of the pipe will exceed the emissions from disposing of the pipe in a landfill and new pipe production. That conclusion is contingent on a market for these uses. Extensive reworking of the pipelines may lead to large quantities of wastes and discharges to the marine environment and fresh water. It will also produce wastes for which there are no known recovery methods. Concrete materials may also be recovered, if there is a use for them. Disposal on land requires a large space and may cause local pollution and contamination of fresh water.

Even when considering theoretical "replacement emissions" the leave in place option has the lowest emissions for all type of gasses (Ref. /3/).

Discharges to Sea or Ground

Removing pipelines reduces discharges to the marine environment of heavy metals and organic compounds with a potential of negative impact. Since impacts from discharges to the marine environment are considered minor even if pipeline are left in place, removal makes no great contribution to the marine environment in the form of reduced inputs of potentially hazardous substances.
For discharges to ground during demolition and recycling on an onshore sight, this is considered minor since it is assumed that the onshore site is protected and has the means to take care of accidental spills during the processes.

Physical Impacts/Effects on Habitat

Habitat restitution time is short when exposed pipelines and cables are removed. The removal of buried, covered or subsided pipelines on a soft bottom may have local effects for habitat along its alignment. The disturbed area is small, and the consequences are seen to be insignificant.

Some organic material (fouling) on pipelines and cables will be taken up and transported to land along with them. Neither the extent nor the use of this kind of material has been assessed.

Aesthetic Impacts

During the onshore demolition and recycling processes, there might be some negative aesthetic impacts. Marine growth attached to the pipelines might cause odor problems, and the process itself might cause visual pollution to neighbors of the site. Compared to other demolition operations including offshore installations like topsides and jackets, the impacts from pipeline demolition will be minor. The demolition process is easy, and it should be possible to structure the work in a way that minimizes the visual pollution. It should also be possible to include working processes, which take care of the organic materials prior to arrival at the demolition site.

Waste/Resource

Removing pipelines is considered the optimal solution seen from a waste/resource point of view. However, this is dependant on the quality and demand for the recycled materials.

Some of the pipelines may contain internal low-radioactive deposits. If steel containing these deposits is sent for melting down without first cleaning, then radioactive dust and slag may result.

The concrete in the coating and the anodes can be expected to be recycled.

Littering

Except for potential loss of small sections during recovery, minimal littering effects are expected since the pipelines are removed.

There will be minimal impact from pipelines that were trenched and naturally covered. Observations indicate that pipelines on sand bottoms will be wholly covered or buried within 10-15 years after being laid (Ref. /2/).

12. FEASIBILITY OF DISPOSAL OPTIONS

Pipeline disposal options are discussed with regard to technical feasibility. These assessments will be kept separate from the cost evaluations.

Leave in place is currently the most common disposal option. Both in U.S. waters and the North Sea, this is the common practice. The U.S. and international regulations do not exclude leave in place as an option. The environmental impacts of leaving the pipelines in place are considered minimal.

Burial/trenching is considered a less preferred option since this option requires increased energy consumption, emissions and costs without having any significant environmental benefit.

Removal by reverse lay barge recovery is probably the best of the removal options. Most of the operations can be completed through remote operations, minimizing personnel involved in the operations. It seems to be a cost and time saving option as well compared to the other options.

Removal by reverse reel barge recovery has a limitation when it comes to sizing and coating. Currently, the maximum diameter of pipes to be removed with a reel barge is 14". This means this option is only valid for a limited number of the pipelines.

Removal by long section barge recovery is also a good removal option in the same way as for the reverse lay recovery method. However, the long section recovery method is only suitable for shallow waters.

Removal by tow recovery and removal by short section recovery both involve a high number of divers and subsea activities. These options are more hazardous, and might not be cost effective. Short section recovery is a slow activity.

J-lift recovery is a good method for pipelines with larger diameters pipelines and deep waters. The option limits the use of divers and subsea operations.

13. CONCLUSION

Regulations

Currently, pipelines in U.S. waters fall under the regulation of the Department of Transportation (DOT) Research & Special Programs Administration Office of Pipeline Safety (RSPA/OPS) and the Minerals Management Service (MMS) of the Department of the Interior (DOI). Currently there are no international rules/laws for the removal and disposal of offshore oil and gas pipelines.

Safety and Risk

In general, this study shows that working accidents in connection with demolition activities dominate the risk to personnel. These activities include diving operations, work on barges with sea fastening and work onshore involving the cutting/disposal of pipe and materials. Barge work, including handling of pipes with marine growth and hydrocarbon residuals provide a large contribution to the total personnel risk.

The risk assessments demonstrate that pipeline removal options, as compared to in-situ (leave in place) and bury/trenching disposal options, carry a greater risk to personnel due to removal options having increased hands on involvement. As a result of these findings, in the event that pipeline removal is necessary, the extent of the work (hands on involvement of personnel) performed offshore either on a barge or during diving operations should be minimized. The increased use of ROVs and other remotely operated equipment can help to obtain this effect.

Even though there remain risks involved with the handling of equipment and pipeline sections, the overall risk to personnel due to pipeline removal operations is relatively small in instances where the use of remotely operated equipment is taken full advantage of and is suitable for the operation. Of the removal techniques studied, those involving reverse lay methods were found to be safer than those involving tow and sectioning methods due to the reduced number of subsea activities involved. The correct handling of pipe with corrosion resistant coatings and having a proper industrial process for materials separation will be essential to minimize the personnel risk during the final disposal phase, which is conducted onshore. Several proposals were made in this report to ensure the operations in the removal and final disposal phase are carried out with proper regard to safety.

Cost

If all of the pipelines currently in service were to be removed after abandonment, the cost associated with this removal would be many times that of leaving in place. The cost of removing and disposing all pipelines is estimated at 16.2 billion dollars. This assumes an average depth in the 200-500 foot range, the reversed lay methodology and that each portion of pipeline is approximately 4 miles long. The cost does not include transport onshore and any further processing or landfill cost. The cost for burial/trenching is estimated at 1.6 billion dollars.

Environmental Impacts

The impacts on the environment and the marine environment from pipelines and cables left in place were found to be very minor. Conversely recovery operations will have a negative impact on the environment. The number of vessels required for removal operations and long operating hours will result in considerably more releases and emissions than leaving the pipelines in place. In addition the energy savings benefit from recycling the pipeline materials will be exceeded by the energy required to remove the pipelines and separate the materials.

Overall conclusion

Currently, there are no regulations that require removal of subsea pipelines if they are not an obstruction to navigation. Based on the high costs for removing the pipelines, the personnel risk involved in the removal operations, the negative effect on overall emissions to air and the very limited reduction in discharges to sea, the overall conclusion is that it is better to leave the pipelines in place. If possible, re-use of the pipelines is the optimal solution.

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