

Markham ST-1 Decommissioning Comparative Assessment for the Pipelines



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1. EXECUTIVE SUMMARY

A Comparative Assessment of pipeline decommissioning options is a key consideration within Decommissioning Programmes submitted to the Department of Energy and Climate Change (DECC).

The Markham field was discovered in 1984 and is a gas field located in the UK Sector of the Southern North Sea and extends over license blocks 49/5a and 49/10b on the UKCS and J3b and J6 on the NLCS. Centrica North Sea Limited owns 27.2%, and Centrica Production Netherlands B.V. owns 10.33% equity in the Markham Field and between them a number of other field partners own the remaining equity.

Preparations need to be made to decommission six wells, the ST-1 platform and pipelines. The ST-1 platform is in the UK sector of the North Sea but two pipelines (one gas export and one methanol supply line) connect it to the J6A (also referred to as Markham in literature) platform situated in the NL sector. Two operating Grove pipelines (10" gas and 2" methanol) cross the ST-1 pipelines near the J6A platform. The two Stamford pipelines (PL2567 and PLU2568) - that are not in use, cross the buried ST-1 pipeline in the NLCS.

The platform exports gas from the Windermere platform (owned by Ineos UK SNS Limited) to J6-A. Current indications are that Windermere will be decommissioned before ST-1.

ST-1 comprises:

- Topsides - 1,300Te
- Jacket – 1,200Te
- Wells - 6
- 12" gas export pipeline to J6A 5.6km
- 2" methanol line from J6A 5.6km clamped to the gas export pipeline

For the most part the gas pipeline and methanol lines are trenched and buried. They remain at a satisfactory depth below seabed level and appear stable. The pipeline and methanol risers are connected to both the ST-1 and J6A platforms in a piggyback¹ arrangement.

There are 19 concrete mattresses over the pipelines at the approach to the ST-1 platform and 20 concrete mattresses over the pipelines at the approach to the J6A platform. The mattresses cover the spool pieces as well as the 30m length of pipeline on the seabed and the 30m transitions between seabed and full trench depth. This corresponds to approximately 88m/93m 12"/2" pipe spools respectively at the ST-1 end, and approximately 49m/52m of 12" / 3"/2" pipe spools at the J6A end [1]. There are a number of what are believed to be sand bags protecting the pipe spools in the vicinity of the bottom of the pipeline risers at both platforms although the exact quantities at each location are not known.

This document summarises a comparative assessment of the most feasible options for decommissioning the ST-1 pipelines.

¹ The 2" methanol line is clamped to the 12" flowline at intervals along their length; the 2in methanol pipeline is approximately 6 metres shorter than the 12in gas pipeline, and this - as well as the configuration of the risers - accounts for the apparent difference in length of pipe spools.

Pipeline and methanol line options

- Complete removal;
- Partial removal, leaving the buried pipelines *in situ* and making safe the ends by cutting and removing the short ends exposed on the seabed and in the trench transition areas.

All options include removal of features such as spool pieces, mattresses and sand bags in accordance with mandatory UK requirements.

In the UK the options were assessed using the DECC Decommissioning Guidance Notes and Centrica Comparative Assessment guidelines. A similar approach has been adopted for elements in the NL sector. During the assessment process, evaluations were made principally on a qualitative basis using Centrica's established corporate risk assessment tables but combined with deterministic values from the cost and energy use estimates.

The results of the assessment showed the risks and impacts of all pipeline options to be broadly acceptable, although the technical and safety risks associated with complete removal of the pipelines would be tolerable rather than broadly acceptable. This is primarily due to there being limited experience in removing trenched and buried piggybacked pipelines [7]. From an environmental perspective lower risks and impacts will be incurred for the partial removal case than for any of the other decommissioning options.

The societal assessment showed that complete removal would be marginally beneficial because of continuation of employment due to extension of vessel use and onshore waste management activities. Although in the short-term, fishing activities might proportionately be disrupted as decommissioning activities increase.

Finally, the partial removal options would cost less to adopt than complete removal.

Therefore, the preferred option identified by this comparative assessment is partial removal for both pipelines in the UK and deferral in NL to the complicating presence of the Grove pipeline crossings. This means that after flushing and left full of seawater the majority of the pipeline and the methanol line will be left *in situ* with no disruption for the majority of their lengths.

In the UK near the ST-1 platform the pipelines will be cut below the seabed and the pipe spools, pipelines on the seabed, and the transition section to a burial depth of 600mm will be removed. The intention is that all the pipeline protection materials such as concrete mattresses and sand bags will be removed.

Options for dealing with the pipelines in the NL sector are complicated by the presence of the Grove pipeline crossings and this has resulted in a preference for deferring some elements of the decommissioning works. Therefore, near the J6A platform only the pipe spools and associated pipeline protection features will be removed. The pipelines and associated protection features will remain where they are and dealt with when J6A is decommissioned.

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TERMS AND ABBREVIATIONS

ABBREVIATION	DESCRIPTION	ABBREVIATION	DESCRIPTION
ALARP	As Low As Reasonably Practicable	MM	Million
Broadly Acceptable / Low ²	Risk are broadly acceptable but controls shall be subject to continuous improvement through the implementation of the HSEQ Management System and in light of changes such as technology improvements	NB	Nominal Bore
Centrica	Centrica Production Nederland B.V; Centrica North Sea Limited	NLCS	Netherlands Continental Shelf
CO ₂	Carbon Dioxide	NORM	Naturally Occurring Radioactive Material
DECC	Department of Energy and Climate Change	NUI	Normally Unattended Installation
DSV	Dive Support Vessel	OGUK	Oil & Gas UK
Free span	A pipeline is called to be at free span when a pipe segment is not supported by the seabed.	Pipeline(s)	12" gas pipeline and 2" methanol lines, either individually or clamped together
HAZID	Hazard Identification Workshop	rMCZ	Recommended Marine Conservation Zone
HSE	Health, Safety and Environment	ROV	Remotely Operated Vehicle
in (")	Inch (25.4mm)	cSAC	candidate Special Area of Conservation
Intolerable / High ²	Impacts are intolerable. Controls and measures to reduce impact to ALARP (at least to Medium) and require identification, documentation, implementation and approval.	SSM	State Supervision of Mines (NL)
km	Kilometre(s)	ST-1	Markham ST-1 Platform
KP	Kilometre Post	SWOT	Strengths, Weaknesses, Opportunities and Threats
LAT	Lowest Astronomical Tide	Te	Tonne(s)
m	Metre(s)	Tolerable / Medium ²	Risks are tolerable and managed to ALARP. Controls and measures to reduce risks to ALARP

² The colour of this highlighted cell is used in the assessment tables

ABBREVIATION	DESCRIPTION	ABBREVIATION	DESCRIPTION
			require identification, documentation and approval by responsible leader
Median Line	Intersection of UK & NL country boundaries	UK	United Kingdom
		UKCS	United Kingdom Continental Shelf

2. INTRODUCTION

2.1 Overview

The Markham field was discovered in 1984. It is a gas field located in the UK and NL sectors of the Southern North Sea and extends over license blocks 49/5a and 49/10b on the UKCS and J3b and J6 on the NLCS.

Centrica North Sea Limited owns 27.2%, and Centrica Production Netherlands B.V. owns 10.33% equity in the Markham Field and between them a number of other field partners own the remaining equity.

The Markham field has been developed with facilities in the UK sector (ST-1 Platform) and facilities in the Dutch sector J6A and Compression Tower. Preparations need to be made to decommission ST-1 platform and pipeline and to plug and abandon the wells. The ST-1 platform is in the UK sector of the North Sea but a pipeline connects it to the J6-A platform situated in the Nederland sector. The components of ST-1 are:

Description	Quantity (Total)	Quantity (UK)	Quantity (NL)
Topsides	1,300Te	1,300Te	0Te
Jacket	1,172Te	1,172Te	0Te
Piles	662Te	662Te	0Te
12in gas export line	5.6km	2.4km	3.2km
12in pipe spools	137m	88m	49m
2in Methanol Line	5.6km	2.4km	3.2km
2in pipe spools	145m	93m	52m
Sand bags ³	1,000	500	500
Concrete Mattresses	39	19	20

Table 2.1: ST-1 Components

There are two primary interfaces with other infrastructure:

- J6-A Platform (via 12" Gas Export Pipeline & 2" Methanol line); 5.6km
- Windermere via 8" Gas Import Pipeline & 2" Umbilical; 6.4km

Following public, stakeholder and regulatory consultation the ST-1 Decommissioning Programmes will be submitted in the UK in full compliance with the DECC Guidance Notes [6]. These documents will also be submitted to SSM in support of decommissioning proposals in the Dutch Sector. The ST-1 Decommissioning Programmes [1] explain the principles of the removal activities and are supported by an environmental impact assessment [3] and this comparative assessment.

The trenched pipeline and piggybacked methanol line crosses the southerly corner of the Cleaver Bank SAC in the Dutch Sector. Details of SAC and all other relevant environmental baseline data related to the area are provided in the environmental impact assessment [3].

The ST-1 platform was installed in 1994 and is a NUI supported by a four leg steel jacket in a

³ The number of sand bags has been crudely estimated based on sketches; the exact number has not been quantified. Furthermore, although the term sand bags has been used throughout the documentation it is not known whether this explicitly refers to 'sand bags' or 'grout bags'.

water depth of 31m LAT. Comingled gas from Windermere and ST-1 is transported from ST-1 to the J6-A facility where it undergoes final processing before the resulting produced gas is exported to the Netherlands through the Westgastransport (WGT) pipeline system.

The pipeline and piggybacked methanol line risers are clamped in a piggyback arrangement up onto both ST-1 and J6A.

Figure 2.1 shows the ST-1 and J6A infrastructure and the battery limits

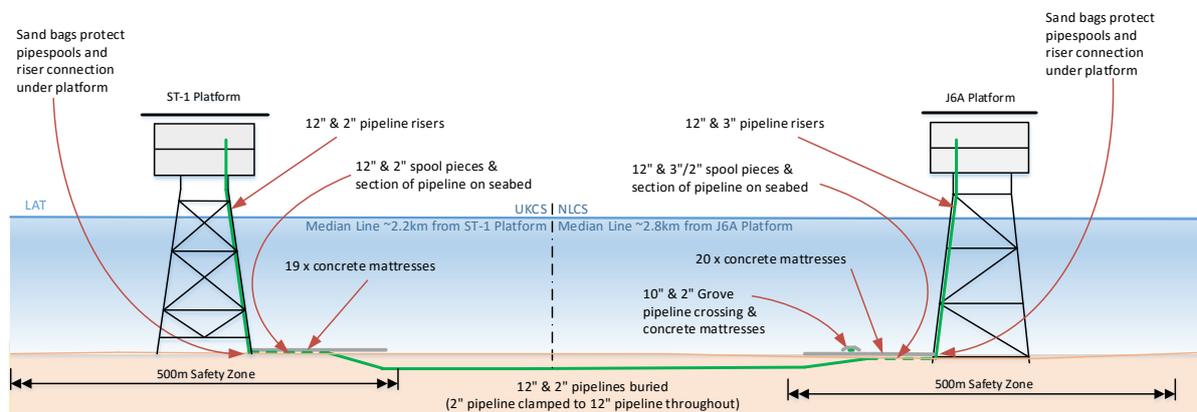


Figure 2.1: ST-1 installation & pipelines prior to decommissioning

Pipeline and Methanol Line (Pipelines)

The pipelines are trenched with naturally backfill along their length. Details of depth of burial are provided in Figure 7.1 in the appendix. The DECC Guidance Notes state that in most cases burial or trenching to a minimum depth of 0.6m above the top of the pipeline is necessary for pipelines decommissioned *in situ*. The pipeline was S-lay installed. That is, the pipeline joints were welded on the lay vessel as the pipeline was placed on the seabed before a channel was trenched for the pipeline. For the most part the pipelines are trenched to a depth greater than 1.0m and have naturally filled back to seabed level, excluding the transition sections at the platform approaches which covered by mattresses.

2.2 Purpose

The purpose of this document is to present a comparative assessment for the ST-1 pipelines, concrete mattresses and sand bags in support of the ST-1 Decommissioning Programmes [1]. The document describes the decommissioning options considered, the method used in the comparative assessment, and the findings using the DECC [6] and Centrica Guidance Notes [5].

3. DECOMMISSIONING OPTIONS

The options detailed in this section are those that have been included in the comparative assessment process. The pipeline and methanol line are piggybacked and connected by a series of clamps along their length. Therefore, the options for decommissioning are dependent. Therefore, both pipelines have been considered as one unit. There would be complications associated with separating the pipelines should they be recovered.

There is an implicit assumption that options for re-use of the pipelines have been exhausted prior to the facilities moving into the decommissioning phase and associated comparative assessment; therefore, this option has been excluded.

The options considered for decommissioning the pipelines are:

- **Complete removal** – Complete removal of the pipelines by reverse installation using the

reverse reeling technique⁴.

- **Partial removal** – Leaving the majority of both the pipelines *in situ* underneath existing burial cover. Pipeline end section at ST-1 will be cut and removed from the point in the trench transitions where the pipeline is determined to be at an acceptable depth below the seabed such that it does not present a risk to other users of the sea.

For both options the Grove flowline crossing and associated mattresses (12 mattresses and a length of pipeline) would remain. This section comprises the trench transition section of pipelines at J6A. The spools at both ends and associated mattresses and sandbags would be removed (8 at J6A and 19 at ST-1).

The pipeline decommissioning options are shown pictorially in Figure 3.1 & Figure 3.2.

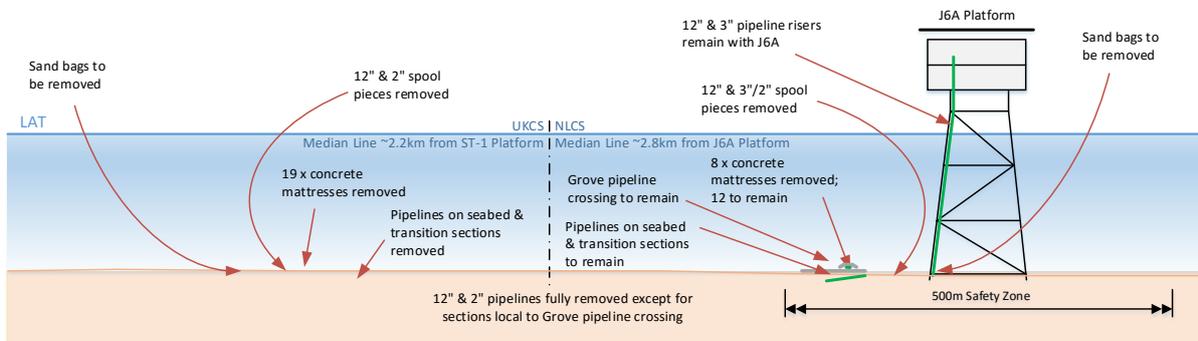


Figure 3.1: Complete removal of both pipelines

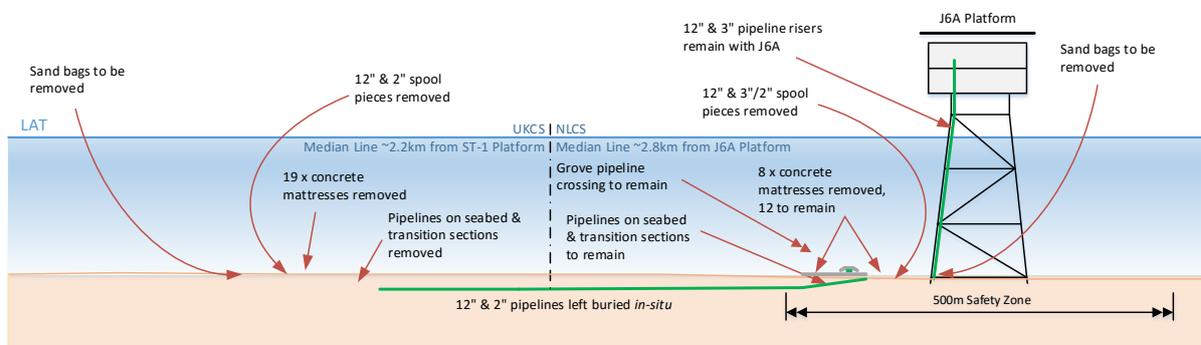


Figure 3.2: Pipeline and methanol line partial removal

Further details of the pipeline decommissioning options are shown in Table 3.1. The majority of the activities detailed in these tables are expected to be undertaken with a dive support vessel (DSV), except the full removal of the buried pipelines, which would be undertaken by DSV and a pipelay vessel.

⁴ The reverse reeling technique would involve recovering the pipelines to two separate pipe reels on a pipelay vessel and thereafter offloaded and cut into manageable lengths onshore

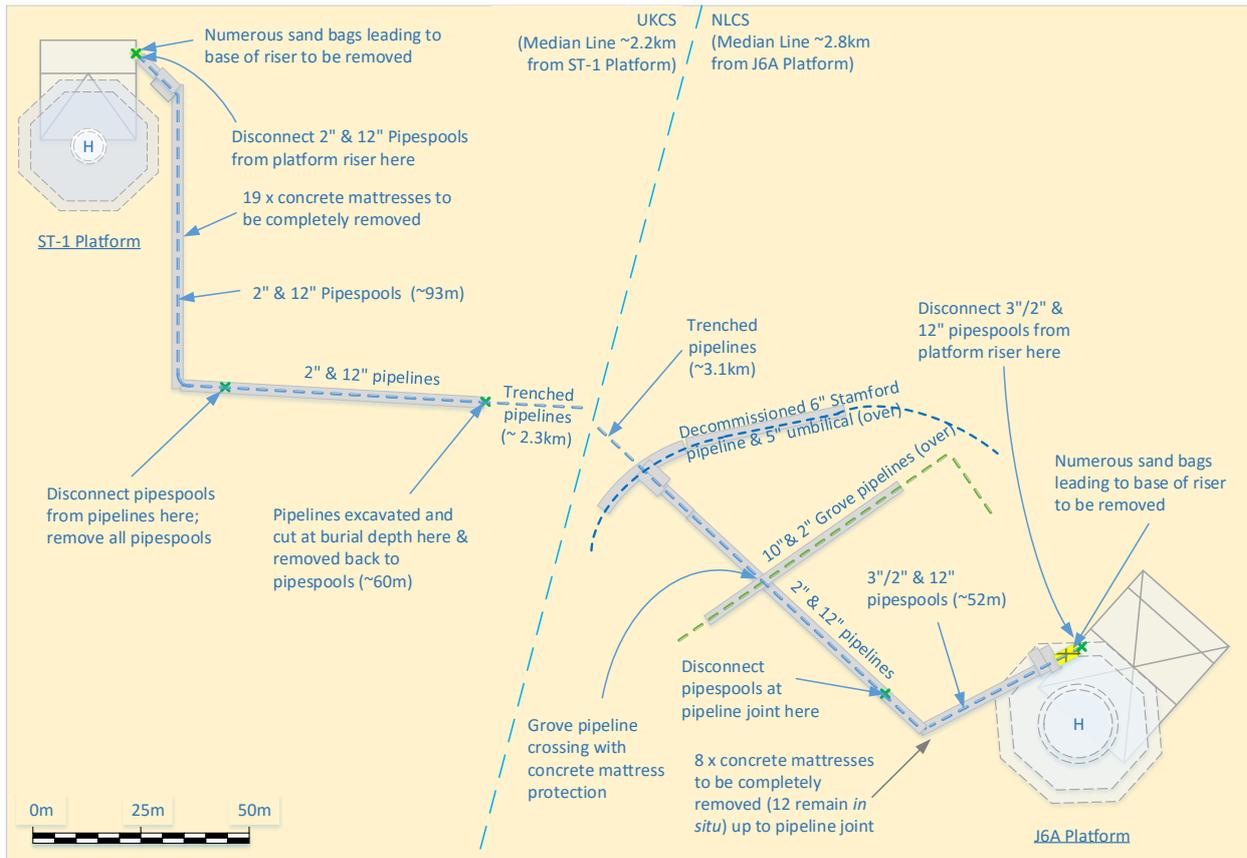


Figure 3.3: Pipeline and methanol line end cut locations

Item	Option 1 Complete Removal	Option 2 Partial Removal
Buried pipelines	Remove. Reverse installation of the pipelines using DSV. Uncover the pipe ahead of removal operations using dredging machine; recover pipelines with a winch through a stinger to the pipelay vessel. Remove piggy back clamps to allow separation of the 2in & 12in pipelines reel onto spools. Return pipes to shore for processing.	Leave <i>in situ</i> . No work
Pipeline ends, exposed or insufficiently trenched, approx. 60m at ST-1 (UK) Leave pipeline ends 'as-is' at J6A in vicinity of Grove pipeline(s) crossing (NL)	Remove. Recover using pipelay vessel as part of reverse reeling process.	Cut and remove. Use divers from DSV to unbolt buried pipelines from risers, excavate local areas to give access for cutting pipeline (UK only) and allow seabed to backfill naturally. This may also involve local water jetting.
Pipeline spool pieces at ST-1 and J6A	Remove. Divers disconnect flanges and rig spools for lifting to DSV	Remove. As option 1.

Table 3.1: Pipeline and methanol line decommissioning options

3.1 Decommissioning of the concrete mattresses

The intention is to remove all of the concrete mattresses. The concrete mattresses are Dunlop 'Linklok' type mattresses. These are made of articulated blocks that are constructed by casting concrete into hard plastic honeycombed (in the case of ST-1) moulds, with polypropylene rope or nylon rope used to link the blocks together. The concrete density can be varied to achieve the weight of the mattresses as required. In the case of ST-1 the mattresses are 3m wide x 6.12m long and 150mm thick. The nominal mass of each mattress in air is 4,630kg.

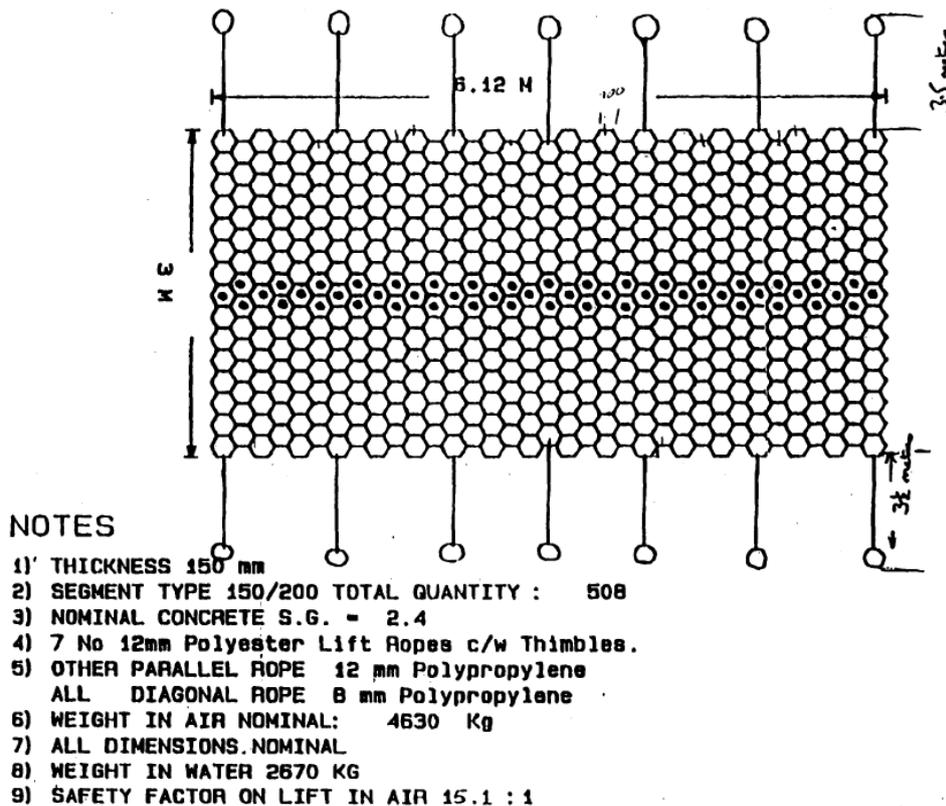


Figure 3.4: 'Linklok' Mattresses used on ST-1 Pipeline

'Linklok' style mattresses have not commonly been used since the 1990s [8].

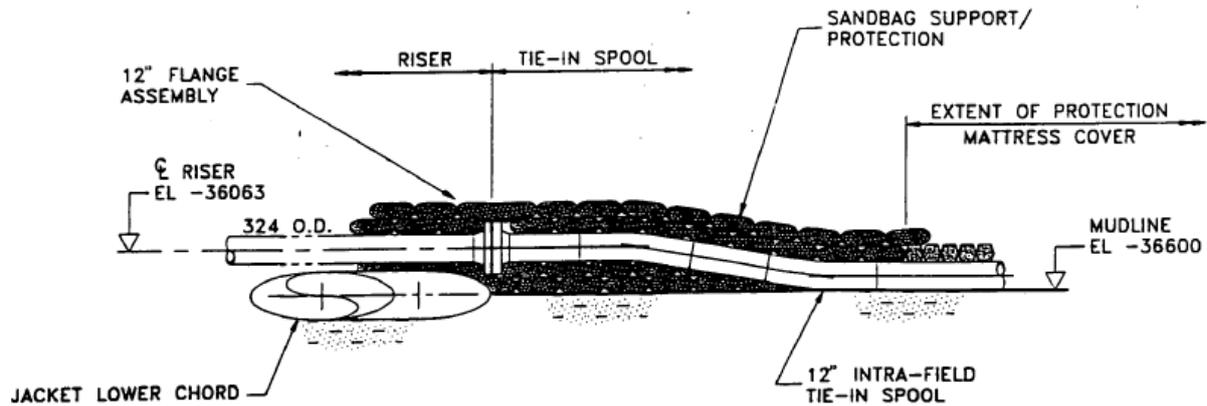
The recoverability of a mattress is heavily influenced by its condition. Mattresses that have become degraded are more difficult and dangerous to recover and have less scope for re-use once recovered. In this case, however, we believe that their condition will allow recovery of the concrete mattresses.

3.2 Decommissioning of the 'sand bags'

The number of sand bags has been estimated based on sketches as the exact number was not quoted in the original design specification. Furthermore, although the term 'sand bags' has been used throughout the documentation it is not known whether this explicitly refers to 'sand bags' or to 'grout bags'. Some references are made to 'grout bags' but the majority of reference data refer to 'sand bags'.

The original design records allow for the deployment of 5m³ of sand bags, and this is equivalent to a total of approximately 200 'sand' bags and between 250 and 300 'grout' bags (higher density smaller volume per bag.).

The original design specification states that 'nylon/polyester type bags' were used and they were 25-30kg bags. The bags were originally deployed to the local vicinity using large 'deployment' bags or 'cargo nets' and then man-handled and installed locally by divers.



TYPICAL SECTION AT SANDBAG PROTECTION
(SECTION AT J6-A PLATFORM DRAWN)

Figure 3.5: Typical Section of Sand Bag Protection at J6A (not as-built)

The intention will be to remove all of the sand bags when decommissioning the pipelines.

At ST-1 the sand or grout bags can be recovered from the seabed after the jacket has been removed, and this will allow a number of different methods to be used. The J6A jacket will remain in place, and this will reduce the efficacy of mechanical devices being used to recover the sand bag materials. In other words, underneath J6A divers will be required to man-handle the bags from the area.

From a practical perspective it is expected that the bag material will have remained largely intact.

4. COMPARATIVE ASSESSMENT FOR PIPELINES

4.1 Method

The majority of the comparative assessment is qualitative, carried out at a level sufficient to differentiate between the options. However, in some cases, such as cost, it is necessary to examine the differences in more detail to provide clarity. The comparative assessment considers the following generic evaluation criteria and specific sub-criteria in line with DECC and Centrica Guidance [6] and [5]:

- Health & Safety:
 - Health & Safety risk to offshore project personnel
 - Health & Safety risk to other users of the sea
 - Health & Safety risk to onshore project personnel
- Environment:
 - Environmental impacts of operations
 - Legacy environmental impacts
 - Gaseous emissions (CO₂) (quantitative)
 - Energy use (Giga-Joules) (quantitative)
- Technical:
 - Risk of major project failure
- Societal:
 - Effect on commercial activities
 - Employment
 - Communities or impact on amenities
- Cost

Scoring is achieved using risk matrices, with high figures indicating high risk and less desirable outcomes. High costs also attract a high score. It should be noted that societal score looked at beneficial outcomes as well as detrimental outcomes.

The following paragraphs describe the philosophy and processes followed for the Comparative Assessment using generic, high level evaluation sub-criteria. The results of the assessment are summarised in Section 5.

4.2 Health & Safety

Definition: An assessment of the potential health and safety risk to people directly or indirectly involved in the programme of work offshore and onshore, or who may be exposed to risk as the work is carried out. Health and safety risk is assessed using three specific sub-criteria.

Sub-criteria:

1. The health and safety risk for project personnel who would be engaged in carrying out decommissioning activities offshore are presented in Table 4.1:

Example Description of Hazard	Who is at risk?
Loss of dynamic positioning leading to uncontrolled movement of vessel and pipeline(s), hydrocarbon release	Diving personnel underwater
Vessel-based lifts, structural integrity of pipeline sections not verified before recovery, leading to failure of pipeline of components of the lifting equipment	Vessel based personnel
Sudden movements during pipeline recovery works leading to dropped objects or swinging loads	Diving personnel, vessel based personnel, vessel based assets (e.g. Remotely Operated Vehicles)
Limited experience surrounding process for recovering trenched and buried pipelines [7]. Complications associated with separating the pipelines as they arrive on the vessel resulting in the pipeline(s) parting or buckling during reverse reeling operations; uncontrolled movement of pipelines and associated reeling and recovery equipment	Vessel based personnel
Collision between vessels and offshore structures due to mix of shipping lane traffic, product transport vessels, supply and maintenance barges and boats, drifting boats	Offshore personnel and assets
Residual hazardous materials such as methanol, chemicals from umbilical cores, wax deposits, hydrocarbons or NORM from within pipelines released to the local marine environment	Divers and vessel based personnel

Table 4.1: Description of offshore hazards

2. The residual risks to marine users on successful completion of the assessed decommissioning option are presented in Table 4.2:

Example Description of Hazard	Who is at risk?
Exposed pipeline or umbilical sections leading to snagging risk	Other users of the sea, predominantly fishing vessels

Table 4.2: Description of residual hazards to mariners

3. The safety risks for project personnel who would be engaged in carrying out decommissioning activities onshore are presented in Table 4.3:

Example Description of Hazard	Who is at risk?
Residual hazardous materials such as methanol, chemicals from umbilical cores, wax deposits, hydrocarbons or NORM from within pipelines released to the local onshore environment	Hazardous or toxic substances affecting onshore personnel
Onshore cutting – sharp edges and repetitive operations when dismantling pipelines	Onshore personnel
Unplanned sudden movements during pipeline dismantling works leading to dropped objects or swinging loads	Onshore personnel

Table 4.3: Description of onshore hazards

Assessment of sub-criteria:

The difference in potential safety risks between the options is sufficiently large that a HAZID was not deemed to be required at this stage. A Hazard Identification (HAZID) workshop will be carried out when the selected option is developed in more detail. For the purposes of the comparative assessment in lieu of a HAZID a high level review of the differences was undertaken and correlated to the duration of activities that would be required.

As many of the hazards are common between the complete removal and the partial removal options, only those hazards giving rise to difference between the options were assessed.

Examples of this are:

- Where a hazard exists for one option but not the other (e.g. risks relating to pipeline failure during reverse reel lay recovery or hazard associated with separating the two pipelines as they arrive at the pipelay vessel)
- Where the hazard exists for both options but is different in magnitude (e.g. risks relating to dropped objects if whole pipeline is recovered to shore to be cut into transportable pieces)

From this a discussion of the key contributors to the differences between options - the differentiators, is presented below.

Pipeline (and Methanol Line) Assessment*Safety Risk to Offshore Project Personnel*

The key differences between the options are as follows.

- Risk to divers and personnel on vessel from hydrocarbon or hazardous substance releases from recovered pipelines will be greater for complete removal than for partial removal due to the larger volume of material that would be recovered;
- Risk associated with reverse reeling operations, with the pipelines needing to be separated as they arrive at the pipelay vessel, and risks associated with the vessel being attached to the pipelines. The risk to personnel and assets are greater for complete removal option compared to partial removal option where only pipeline sections will be cut and lifted;
- Increased risk to all activities due to adverse weather is greater for complete removal than for partial removal as the time the vessel would be in the field is greater for complete removal than for partial removal;
- Risk associated with legacy survey activities that is, the risks associated with vessels being used is greater for partial removal than for complete removal. Typically, in the UK a minimum of two legacy surveys would be required to confirm the condition of subsea facilities left *in situ*. It is expected that there will be a similar requirement for legacy surveys in NL.

Given that the activities and techniques are frequently used in the North Sea, it is presumed that the risks from all hazards are broadly acceptable. It is acknowledged that there is little experience of reverse reeling a trenched and buried piggybacked pipeline and we believe therefore this risk could be higher but still tolerable if sufficient mitigation and control measures are adopted. This risk relates only to the complete removal option.

Residual Safety Risk to Fishermen and Other Marine Users

The greatest risk relating to marine users was likely to be concerned with snagging of fishing gear. The types of fishing in the area is predominantly trawler activity and targeting demersal fish. Therefore, there is a potential for snagging on equipment left on the seabed, including spoil mounds. Data relating to pipeline and methanol trenching and burial status are shown in Figure 7.1 in the appendix. The data shows that the pipeline and methanol line are trenched and buried consistently to a depth of greater than 0.6m and inspection data show that there has not been a history of free spans along the pipeline.

From this it can be reasoned that decommissioning activities that minimise the disturbance to the seabed, reduce the likelihood of creating snag hazards / spoil mounds and that leave the seabed free of equipment will minimise the impact on local fishing activities; this will be no different from the current situation. Both complete removal and partial removal will leave the seabed free of equipment. Although the complete removal option has the potential to leave spoil mounds that present snagging hazards, it is possible that with extra effort these could be dispersed, or they would disappear over time.

Health & Safety Risk to Onshore Project Personnel

The key differences between the options are as followed:

- Risks associated with cutting the pipeline resulting in injury are greater for complete removal due to the higher quantity of material returned to shore compared with the partial removal option;
- Risks associated with lifting and handling pipeline sections are also greater for complete removal, due to larger quantity of material being returned to shore.

Summary

Many of the hazards described above are common to both decommissioning options. Based on the differences, the partial removal option gives rise to lower risks to personnel for the following three reasons:

- Less offshore work;
- Less onshore handling;
- Little experience in the removal of trenched and buried piggybacked pipelines in the North Sea [7], resulting in an increase in perceived risk.

By completely removing the pipelines the risk of snagging is removed in perpetuity. Therefore, the complete removal option results in lower residual risks to mariners and other users of the sea.

There is likely to be no increased snagging risk associated with the partial removal option due to the burial status of the pipeline (Figure 7.1). However surveys will need to be done in future in order to verify that the risk of snagging remains low for the foreseeable future.

Table 4.4 summarises this assessment. The colour coding (green being best) indicates whether the risks are broadly acceptable or tolerable. It should be noted that these risks are for the *differences* between options only.

Sub-Criterion	Option 1 Complete Removal	Option 2 Partial Removal
Health & safety risk offshore project personnel	More offshore work than partial removal. Little experience in the North Sea of reverse reeling trenched and buried piggybacked pipelines [7]. Assessed as medium / tolerable as a result.	Less offshore work than complete removal. Experience in the North Sea of removal of pipeline sections.
Health & safety risk to mariners	Marginally lower risk as potential snag hazards completely removed, although there is a possibility of creating spoil mounds that could present a snagging hazard. These will be dealt with during the decommissioning activities.	Degradation of the remaining pipeline will occur over a long period of time within seabed sediment and is not expected to represent a hazard to other users of the sea. Although the pipeline(s) are buried they could be preserved, resulting in a slightly higher legacy risk of potential snagging, although this is unlikely.
Safety risk onshore project personnel	Significantly more onshore cutting, lifting and handling associated with disposal of the pipelines presents an increased safety risk to personnel	Less onshore cutting, lifting and handling

Table 4.4: Safety assessment for the pipeline and umbilical

4.3 Environmental

The comparative assessment uses four sub-criteria for the assessment of environmental impacts. These are described below.

Definition: An assessment of the significance of the risks/impacts to the environmental receptors as a result of activities or the legacy. Environmental impact is assessed using four specific sub-criteria.

Sub-criteria:

1. Environmental impacts of operations
2. Legacy environmental impacts
3. Gaseous emissions
4. Energy use

Assessment of sub-criteria:

The environmental assessment considers the impacts of the decommissioning options. The findings were summarised in an environmental management worksheet and these formed the input to the comparative assessment.

Only the *differentiators* between decommissioning options were included in the overall score.

The sub-criteria are qualitative and assessed according to the Centrica Environmental Impact Assessment matrix [5]. Addition information to support the conclusions for energy use and the associated emissions to air (Complete Removal with 2,724 tonnes of CO₂ and Partial Removal with 2,654 tonnes of CO₂) and can be taken from a comparison of the estimated emissions against national figures; being relatively low when put into the context of emissions from the UKCS 20,671,000 tonnes CO₂. The numbers are similar and the effect on the overall environmental scoring is trivial.

A full assessment of the environmental impacts of the selected decommissioning option can be

found in the Environmental Impact Assessment [1].

Sub-criteria definitions:**1. Environmental impacts of operations**

The severity of environmental risks associated with unplanned events or the impact to the marine and terrestrial environments from planned operational events.

2. Legacy environmental impacts

The severity of environmental risks associated with unplanned legacy events or the impact to the marine and terrestrial environments from planned legacy activities.

3. Gaseous emissions (CO₂)

The total emissions of CO₂ from the proposed offshore and onshore activities associated with the complete programme of work for each option. This includes all the “direct” emissions from vessel use and the transportation, treatment, recycling and disposal of any recovered materials or waste. It also includes an estimate of the “indirect” emissions that would arise during the new manufacture of material that would theoretically be required to replace otherwise recyclable materials that were deliberately not recovered or recycled.

4. Energy use

This concerns the total predicted (estimated) energy use required to complete the offshore and onshore programme of work for each option. This includes all the “direct” energy used from vessel use and the transportation, treatment, recycling and disposal of any recovered materials or waste. It also includes an estimate of the “indirect” energy that would theoretically be required for the manufacture of new material to replace otherwise recyclable materials that were deliberately not recovered or recycled.

Note that the emissions to air and energy requirements are *representative*, although not exactly the same, of the fuel and energy input data used for waste handling activities.

The environmental assessment was developed by identifying the interactions with the environment for the activities required for each of the options. Activities that were not differentiators were screened out. Those remaining activities with associated interactions with the environment were assessed for consequence and duration to ascertain the potential level of significance of the environmental impact. The interactions with the environment were grouped into the four comparative assessment sub-criteria. The scores were averaged to give a score for the sub-criteria.

Pipeline and Methanol Line Assessment

The assessment of decommissioning the pipeline and methanol line considered the key activities which resulted in differences in the level of impact to the environment. These were:

- Durations of vessels used in the field for the decommissioning activities and legacy surveys. The interactions with the environment (activity which has the potential to impact the environment) which differed between options were:
 - liquid discharges from vessels
 - noise in water from vessels
- Amount of cutting, lifting and disposal required. The interactions with the environment which differed between options were:
 - liquid discharges to sea
 - liquid discharges to surface water
 - noise in water
 - seabed disturbance
 - resource use – landfill space

- Emissions to air
- Energy requirements

The duration vessels are required in the field for the partial removal option is estimated to be 22.5 days and 34 days for the complete removal. Therefore, this is reflected in the liquid discharges to sea, noise, emissions to air and energy requirements. Conversely the legacy survey requirements for partial removal are greater than for complete removal.

The amount of cutting, lifting and disposal requirements are related to the length of pipeline to be recovered. Therefore, the discharge to sea, discharges to surface water, noise in water from cutting, seabed disturbance from lifting, and the use of landfill space are all greater for complete removal than for partial removal.

Estimated emissions to air and energy requirements showed that there is a difference between options. However, the gap between complete removal and partial removal narrows when indirect emissions and energy requirements – such as that required for replacement of unrecovered material – are taken into account.

Sub-Criterion	Option 1 Complete Removal	Option 2 Partial Removal
Environmental impacts of operations	Although the impacts (discharges to sea and noise from vessels and cutting, disturbance to the seabed, disposal requirements) are localised, the duration of the activities is longer than for partial removal option which puts the assessment into the medium region, where additional controls and mitigation measures are required.	Assessed as broadly acceptable due to shorter duration of vessel use.
Legacy environmental impacts	Assessed as no environmental significance due to no legacy survey requirements.	Some environmental significance due to vessel use associated with legacy survey requirements.
Gaseous emissions (CO ₂)	Greater environmental significance due to longer duration of vessel use (direct emissions).	Lower environmental impact due to shorter duration of vessel use (direct emissions).
Energy use (GJ)	Greater environmental impact due to longer duration of vessel use (direct emissions).	Lower environmental impact due to shorter duration of vessel use (direct emissions).

Table 4.5: Environmental assessment for the pipeline and methanol line

The significance of the impacts associated with the interactions with the environment was assessed using the Environmental Impact Matrix in the comparative assessment guidance document [5]. This was done to allow an understanding of the significance of the impacts and to aid decision making where conflicts arose between assessment criteria and sub-criteria. These are reflected in the traffic light colour coding. The results are presented in Table 4.5 with a more detailed breakdown available in Appendix B.2.

The yellow rating for complete removal in the above table is driven by the duration of vessel activities. The factors include liquid discharges to surface water from waste management activities, noise in water, and extent of seabed disturbance as a result of removing the pipeline from its buried position.

4.4 Technical

The technical aspect of the assessment is concerned with the risk of major project failure. Technical feasibility confirms whether the approach being assessed is physically possible given

the technical issues to be addressed.

The technical evaluation is simply the application of a measure to express the complexity of a job, which can be expected to proceed without major consequence, or failure, if it is adequately planned and executed.

Assessment

Both decommissioning options are technically feasible. The technical option for complete removal of the pipeline is by reverse reeling, a reverse method of installation. This involves uncovering the pipelines, lifting the pipelines up out of the trench, onto the back of a vessel and onto two separate spools.

There is limited experience in reverse reeling piggybacked trenched & buried pipelines in the UKCS [7], and as such the technical uncertainty was deemed likely to have an adverse impact on technical risk. That is, technical feasibility and practicality is tempered by the 2” methanol line being piggybacked onto the 12” pipeline, and this complicates the pipeline recovery process. The alternative is that the pipeline would need to be recovered in sections using ‘cut and lift’, but although feasible, we considered that the length of pipeline renders the ‘cut and lift’ approach impractical.

In contrast, partial removal requires approximately 60m of the pipeline ends in the UK sector to be cut and lifted⁵. This is a well-established activity with little technical uncertainty. This option has been widely used for removing shorter sections of pipe, either for the removal of a short pipeline in its entirety, or when discrete sections are being removed for decommissioning. It is usually the recommended removal option for short sections of pipe when it is impractical or prohibitively expensive to mobilise major equipment for removal.

For the ST-1 pipeline and methanol lines to be removed, either in their entirety or the end sections only, they must be removed from the backfill. This can be achieved by either pulling it through the seabed material or by removing the material first by jetting. Reverse reeling a buried pipeline with a piggybacked methanol line adds further uncertainty as there is limited previous experience of this [7]. Jetting to remove the cover has been widely used for short lengths of pipeline, although this would be more time consuming and costly for the entire pipeline.

The technical uncertainties associated with the pipeline decommissioning options have been assessed using the Risk Assessment Matrix in the comparative assessment guidance document [5], the results of which are presented in Table 4.6 below. A more detailed breakdown can be found in Appendix B.1.

Sub-Criterion	Option 1 Complete Removal	Option 2 Partial Removal
Technical feasibility	Limited experience in the North Sea of reverse reeling of trenched & buried piggybacked pipelines in UKCS [7], ‘cut and lift’ method to be avoided.	‘Cut and lift’ method can be used for short sections of pipe.

Table 4.6: Technical assessment for pipelines

As noted, the medium / tolerable rating is driven by uncertainties in the probability of success of the reverse reeling operation, which is considered to present risks to the delivery of the project.

⁵ In order to minimise complications associated with the Grove pipeline crossing in NL the equivalent 60m length of section of pipeline would remain in place due to the presence of the Grove pipeline crossings. It will be dealt with when the J6A platform is decommissioned.

4.5 Societal

Definition: An assessment of the significance of the impacts on societal activities, including offshore and onshore activities associated with the complete programme of work for each option and the associated legacy impact. This includes all the “direct” societal effects (e.g. employment on vessels undertaking the work) as well as “indirect” societal effects (e.g. employment associated with services in the locality to onshore work scope, accommodation, etc.).

Sub-criteria:

1. Effects on commercial activities
2. Employment
3. Communities or impact on amenities

Assessment of sub-criteria:

A qualitative assessment has been undertaken to differentiate between options from a societal perspective. This was undertaken through review of relevant data, discussion and textual descriptions.

Pipeline and Methanol Line Assessment

The assessment of the other criteria (safety, environment, cost and technical) considers the level of detrimental effect whereas the assessment of impacts on employment assesses the level of benefit, a positive effect. Vessel use duration can be used as an indicator of magnitude of the continuation of employment.

The societal issues around the pipelines are discussed below.

Commercial activities

The main commercial activity in the area is fishing. The potential effects could be loss of fishing revenue due to exclusion from fishing grounds, disturbance of the seabed or loss or damage of fishing equipment.

While the vessels are present in the field and activities are being undertaken the area will not be accessible for fishing. Therefore, the magnitude of the impact on commercial activities is related to the vessel duration.

Activities which involve removal or reburial will implicitly disturb the seabed. Therefore, since complete removal will require more activities on the seabed it will have a higher short-term impact on commercial fishing.

Partial removal will leave infrastructure that presents a potential snag hazard. In this situation there is a greater chance that fishing gear could be lost or damaged and this would have an impact on commercial fishing. However the pipelines are buried and historically there have been no reports of spans, exposures or snagging it is unlikely that the partial removal option will be detrimental to commercial fishing activities.

For both options overtrawl assessments and risk assessments will be done to verify that residual snag hazards will remain low and are unlikely to occur.

Therefore, during decommissioning activities the complete removal option is expected to have a greater impact on fishing activities as it has the longest duration and the greatest amount of activity disturbing the seabed. Partial removal leaves infrastructure *in situ* and, therefore, could present residual snag hazards. Pipeline surveys are to be undertaken to confirm that the pipelines remain buried. While these surveys are being undertaken fishing activity may be disrupted for a short time but the impact can be expected to be minimal. Typically at least two post decommissioning surveys are required; the exact magnitude of the impact will be dependent on the type, frequency and duration of the surveys required.

Employment

The complete removal option has greater vessel duration and waste management requirements and therefore impacts more positively on employment than partial removal. The effect on employment will be the continuation of existing jobs, as opposed to the creation of new opportunities; therefore the significance of the positive impact has been assessed as low.

Communities

The port and the disposal site have yet to be established. However, they will be existing sites which are used for oil and gas activities and hold the required permits for waste management. The communities around the port and the waste disposal sites are therefore, expected to be adapted to the types of activities required and the ST-1 decommissioning will be an extension of the existing situation. Therefore, the effect on communities is not considered a differentiator between options.

Pipeline and Methanol Line Assessment

The results of the pipeline and methanol line assessment are presented in Table 4.7 below.

Sub-Criterion	Option 1 Complete Removal	Option 2 Partial Removal
Commercial activities	Greater short-term effect on fishing activities but no legacy surveys	Smaller immediate impact compared to the complete removal option, but some potential future impact associated with legacy surveys
Employment	Greater vessel duration and waste management requirements compared to partial removal option. Therefore slightly greater levels of employment	Shorter vessel duration and lower waste management requirements compared to complete removal option
Communities	Not a differentiator as existing port and disposal sites will be selected, therefore community not anticipated to materially change from existing	

Table 4.7: Societal assessment for pipeline and methanol line

4.6 Cost

A high-level comparison of the costs for the full removal and partial removal options has been carried out. This shows the difference in incremental cost as being comparable to the other evaluation criteria (i.e. safety, environmental, technical and societal) and it allows an understanding of the significance of the difference.

Assessment

The incremental difference in cost between the complete removal and partial removal is in the region of £1.8MM which is ~60% greater for complete removal than for partial removal.

A high-level breakdown of the costs can be found in Appendix B.3.

4.7 Assumptions, Limitations and Gaps in Knowledge

The most significant assumptions, limitations and knowledge gaps relating to the comparative assessment are listed below. In addition, it should be noted that the presentation of the different categories of risks for comparison has required a degree of engineering judgement.

- No fully quantitative assessment of risk has been undertaken, given the clear differences between the options a qualitative approach has been taken;
- There is limited experience of reverse reeling trenched and buried piggybacked pipelines from the seabed [7], so estimations of the safety risks, technical challenges and cost

implications carry some uncertainty;

- Societal benefits are assumed to be proportional to vessel duration;
- Only a high-level comparison of the costs is used.

5. COMPARATIVE ASSESSMENT SUMMARY

Partial removal is the recommended decommissioning option.

This option has been assessed as having the lowest safety risk, lowest environmental impact and risk, lowest technical uncertainty and lowest cost. Societal was the only criterion where complete removal was assessed as being beneficial and this was due to the potential additional employment opportunities associated with this option.

The biggest differentiators between the complete removal and partial removal decommissioning options are safety and technical elements. Examination of the criteria within these categories shows that the issues relate to:

- Uncertainties as to the reliability of recovering a 12" rigid pipeline with a piggybacked 2" methanol line of unknown condition to the deck of the vessel and effect on those working in close proximity if pipeline fails during recovery or cutting;
- The lack of experience in reverse reeling [7] piggybacked pipelines, leading to higher safety risks and higher probability that the project will significantly over-run in both cost and schedule;
- The large amount of handling and particularly lifting involved in recovering the pipeline to shore, where it will need to be cut and moved in transportable lengths.

It can also be seen that environmental assessment favours leaving the pipeline *in situ*. This is primarily because complete removal would require disturbance to the Cleaver Bank SAC as the pipeline runs through the southern edge at approximately the midway point. Also there is less disturbance to ecosystems from removal activities and less impact associated with emissions to air, discharges to sea, noise and disposal requirements for vessel. These factors were considered to outweigh the impact of the ongoing and occasional surveys needed for the pipeline and methanol line remaining *in situ* after decommissioning.

Asset	Aspect	Sub-Criterion	Option 1 Complete Removal	Option 2 Partial Removal (Ends Only)
Pipeline	Safety	Safety risk to offshore project personnel	Yellow	Green
		Safety risk to mariners	Green	Green
		Safety risk to onshore project personnel	Green	Green
	Environmental	Environmental impacts of operations	Yellow	Green
		Legacy environmental impacts	Green	Green
		Gaseous emissions (CO ₂)	Yellow	Green
		Energy use (Giga-Joules)	Yellow	Green
	Technical	Technical feasibility	Yellow	Green
	Societal	Effect on commercial fisheries	Green	Green
		Employment	Green	Green
		Communities	Grey	Grey
		Cost	Green	Green

Table 5.1: Comparative assessment summary

6. CONCLUSION

The comparative assessment was undertaken with a focus on the decommissioning options for the 12” pipeline and the 2” piggybacked methanol line. The assessments considered five criteria: safety related risks (three sub-criteria), environment (four sub-criteria), technical feasibility, societal effects (three sub-criteria), and cost.

As the pipeline and the methanol line are clamped together, two options were compared for them combined as one: complete removal and partial removal. The assessment found that the partial removal option for the pipeline and methanol line was materially better for safety, environment, technical and cost considerations.

Complete removal option would incur higher cost, unplanned risk and greater short-term impacts on the environment. Offshore there would be an increased risk to safety of personnel and planned environmental impacts associated with transferring and disposing of any recovered material onshore.

By completely removing the pipeline and methanol line the risk of snagging is removed in perpetuity and therefore the complete removal option results in lower residual risks to mariners and other users of the sea. However, residual snagging hazards for the partial removal option can also be considered low on the basis that the pipelines are buried and the exposed ends at the platform approaches to ST-1 - and eventually J6A - will be removed.

Residual snagging risks associated with the partial removal option are likely to remain low, but legacy surveys will be required in order to verify this.

In conclusion, based on the comparative assessment ‘partial removal’ is the recommended option for decommissioning the pipeline and piggybacked methanol line. On this basis the

majority of the pipeline and methanol line will be left *in situ* underneath existing burial cover.

In practice this will mean that the pipe spools will be removed at both ends and the pipeline ends at ST1 will be removed. However, the decommissioning of the pipeline ends in NL at the J6A platform will be deferred due to the complicating presence of the Grove pipeline crossing.

7. REFERENCES

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APPENDIX A PIPELINE & METHANOL LINE BURIAL PROFILES

Appendix A.1 Burial Profile – Pipelines

The 2" pipeline is piggybacked (i.e. clamped) onto the 12" pipeline. Pipeline survey data from 2014 is presented in Figure 7.1 KP0 is located at the pipeline flange at the base of the J6A riser(s), with KP increasing heading west towards the pipeline flange at the base of the ST-1 riser(s). The pipelines show excellent levels of burial along their full length.

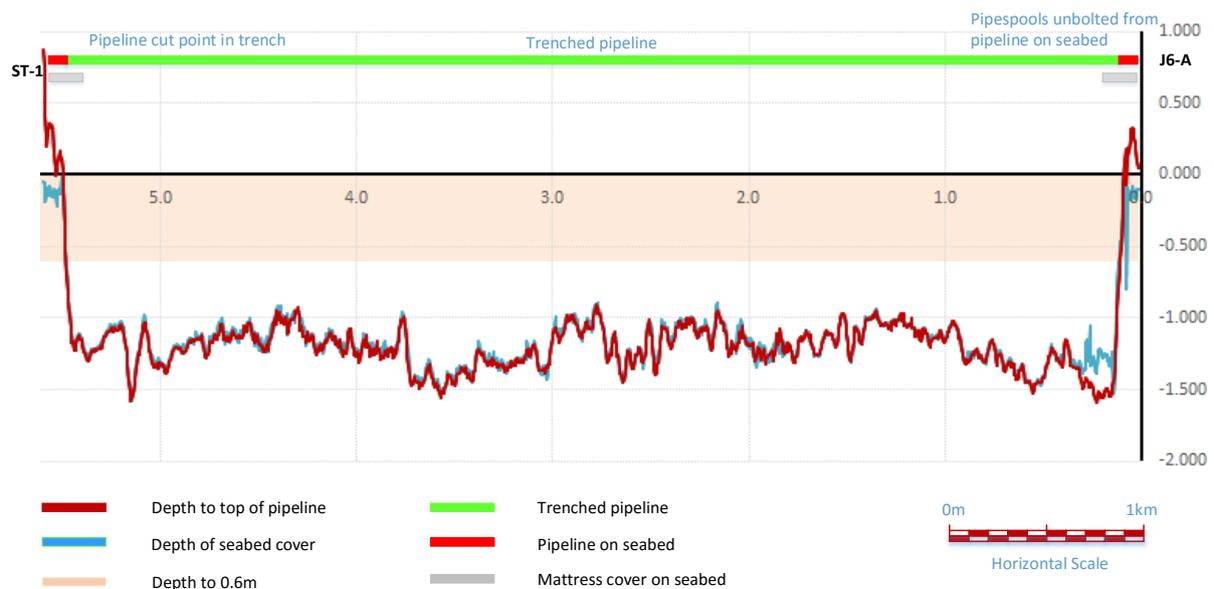


Figure 7.1: Burial profile of ST-1 pipelines

APPENDIX B COMPARATIVE ASSESSMENT TABLES

The following section details the numerical comparative assessment made between decommissioning options. Scores for sub sub-criteria are in accordance with Centrica guidance notes. Sub-criteria scores are calculated by taking the average of each constituent sub sub-criterion. Criteria scores are calculated by taking the average of each constituent sub-criterion (as opposed to the average of each sub-criterion). Numerical scores were derived qualitatively, and are not to be used prescriptively, but rather are given to guide the overall decision by providing an indication of the broad level of acceptability of each sub-criterion.

Sub-criteria are “greyed” when they are not a differentiator.

The assessment was carried out in accordance with the Centrica Comparative Assessment Guidance [5]. Safety criteria were assessed with the HSE Risk Matrix, environmental and societal criteria were assessed with the Environmental Impact Matrix and the technical criteria were assessed with the Project Risk Assessment Matrix.

Appendix B.1 Technical Comparison

	Technically Possible?	Issues (E.g. impact on Safety, Environment, Cost, Reputation and Schedule)	Complete Removal			Partial Removal		
			Severity of Impact	Likelihood of Occurrence	Rating	Severity of Impact	Likelihood of Occurrence	Rating
Removal of pipeline ends	Yes	Very limited, as there is nothing unusual or challenging about the work			0	1	2	2
Jetting of pipeline ends to ensure buried to a sufficient depth	Yes	Limited, routine activity, no expected issues with soil			0	1	2	2
Mass excavation of material covering the pipeline	Yes	Over areas where the pipelines need to be removed. Comprises of activity backfilled material. Fairly routine activity, notwithstanding the length	2	2	6	1	2	2
Reverse reel laying of pipelines	Yes	Pipeline buckling may significantly impact schedule and cost	3	4	12			0
Subtotal					18			6
Subtotal (Average)					9.00			2.00

Table 7.1: Technical comparison

Appendix B.2 Environmental comparison

Subcriteria	Interaction with the environment (Evaluation Criteria)	Activity	Differentiators	Assumptions	Option 1 (Complete Removal)			Option 2 (Decommission in situ)			
					Consequence	Duration	Scr	Consequence	Duration	Scr	
1	Liquid discharge to sea	Water Flushing	No difference	Assuming that the same level of cleanliness is required for both leave in situ and recovery. This might not be the case, depending on the disposal route, handling requirements (occupational health issues) and waste management requirements.							
		Chemical use	No difference	Assuming that the same level of cleanliness is required for both leave in situ and recovery. This might not be the case, depending on the disposal route, handling requirements (occupational health issues) and waste management requirements.							
		Lifting	No difference	Greater number of lifts or a longer duration of lifting the end of the pipeline as it is reeled. All content will be released to sea which ever option is selected.							
		Marine Growth - waste disposal	No difference	Assuming that the pipeline is completely buried and therefore not covered in marine growth.							
		Breaking containment	No difference								
	Liquid releases to sea	From vessels	Duration of vessels in the field is greater therefore the discharges are proportional to the duration in the field.		Discharges unlikely to be detectable.	1	4	8	1	2	3
		From vessels	Duration of vessel in the field is greater therefore there is a greater chance of accidental event (e.g. collision) as it is at sea for longer.			2	2	8	3	1	
		From pipelines	No additional chemicals will be used during the removal activities, therefore the contents of the pipelines is the same with the discharge being either over the duration of the removal for complete removal or over a longer duration as the pipeline breakdown in situ.		The contents of the pipelines is seawater with only limited residues following flushing and cleaning. The consequence of a discharge over a longer time is lower than for the discharge of the whole volume over a short duration.	2	2	8	1	4	8
	Liquid discharge to surface water	From waste treatment onshore	Proportional to the length of pipeline returned to shore.		Discharges of residual fluids onto the waste disposal site could include NORM or heavy metals.	2	4	16	2	2	5
	Liquid releases to surface water	From waste treatment onshore	More waste handling will lead to a greater likelihood of an accidental event.		Relatively small volumes of liquids returned to shore.	2	2	8			
	Noise in air	From onshore waste treatment and disposal	Proportional to the length of pipeline returned to shore.		Assuming the selected yard frequently undertakes cutting, therefore the noise isn't new to the surrounding area, but rather a continuation of the existing.	1	4	8	1	2	3
	Noise in water	Removal	Proportional to length of pipe.		Depends on the method used for complete recovery. Pulling pipeline out of the seabed onto the vessel.	2	4	16	2	2	5
		Vessel use	Proportional to the duration and number of vessels in the field.			2	4	16	2	2	5
	Odour	Maine Growth	No difference		The pipeline is completely buried and therefore not covered in marine growth.						
	Resource use - Ecosystem disturbance	Disturbance of sediment	Proportional to the length of pipeline recovered.		This doesn't consider recovery time.	2	4	16	2	2	5
	Resource use - Physical area	Anchoring	No difference		Assuming pipeline removal vessel (S-lay) is DP rather than anchored.						
		Landfill space	Proportional to the length of pipeline recovered, although the intention would be to recycle as much as possible, in line with the waste hierarchy.		95% of recovered materials recycled.	2	3	7	2	2	5
Socioeconomic use - Removal of safety zone		No difference		No safety zone around the pipeline							
Navigation - removal of hazard		No difference		Pipeline is buried to below 0.6m and there has not been a history of spans. Assuming there are no significance spoil heaps left following overtrawable surveys.							
Subtotal						111			39		
Subtotal Averaged						11			4		
2	General	Survey Vessels	Duration of vessels in the field is greater therefore the discharges, noise, emissions etc are proportional to the duration in the field.		Discharges, noise, emissions unlikely to be detectable.	0	0	0	1	3	6
	Subtotal						0			6	
	Subtotal Averaged						0			6	
3	Gaseous emissions to air	Hydrocarbon Management - blowdown	No difference								
		Hydrocarbon Management - breacking containment	No difference								
		Power Generation - Fuel Combustion	No difference								
		Vessel movements (DSV) - Fuel Combustion	Difference in duration of vessel for removal			2	4	16	2	2	5
		Vessel movements (HLV)- Fuel Combustion	No difference								
		Vessel movements (supply, survey, standby) - Fuel Combustion	Difference in support vessels during removal			2	4	16	2	2	5
		Waste Production - Power generation, biodegration and incineration	Difference in volume of waste returning to shore between options			2	4	7	2	2	5
			Difference in volume of waste returning to shore between options			1	3	6	1	2	3
Difference in volume of waste returning to shore between options				1	3	6	1	2	3		
Subtotal						51			21		
Subtotal Averaged						10			4		
4	Resource use - Energy	Power generation	Proportional to the vessel use duration and the volume of waste sent to shore.		Analogous to gaseous emissions	Analogous to gaseous emissions	0	Analogous to gaseous emissions		0	
		Replacement of material not recovered	Proportional to the volume of material left in situ.								
Subtotal Normalised						0			0		
TOTAL							21			14	
TOTAL Averaged to 3 subcriteria (excluding							7			5	

Table 7.2: Environmental & societal comparison

Appendix B.3 High-Level pipeline decommissioning cost comparison

RESOURCE & ACTIVITY	COMPLETE REMOVAL		PARTIAL REMOVAL	
	DAYS	COST (£K)	DAYS	COST (£K)
DSV Disconnection of pipeline spools, dealing with pipeline ends and stabilisation features such as concrete mattresses & sand bags	22	£2,805	22.3	£2,850
Pipelay Vessel Full recover of pipelines onto spools mounted on deck	12	£1,530	0	£0
Engineering & project management @12.5%	N/A	£542	N/A	£356
Waste Management (onshore)	N/A	£169	N/A	£11
SUB-TOTAL		£5,050		£3,212

Table 7.3: High-level ST-1 pipeline decommissioning costs compared