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Abandonment: Technological, Organisational and Environmental Challenges

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1 Introduction

The decommissioning of offshore installations is a complex multi-disciplined issue, which raises a number of technical, organisational and environmental challenges. The success of a planned decommissioning operation depends on the development of a clear understanding of the complex blend of drivers which control the decommissioning process and their inter-relationship. The drivers usually considered are:

- Occupational Health & Safety (OHS)
- Environmental Public Health & Safety (EPHS)
- Cost
- Technical Feasibility
- Law & Regulation
- Public Perception
- Regional Socio-Economic Issues

The first four, OHS, EPHS, cost and technical feasibility are the primary drivers. The remaining, law & regulation, public perception and socio-economic issues are secondary drivers as they relay on the other primary drivers.

As each decommissioning solution will most likely be different even for similar installations in different locations, the greatest challenge of all is the correct blending of the above mentioned drivers to present the optimum solution to satisfy all interested parties and stakeholders. The optimum solution will most likely result in a compromise resulting from careful weighting and balancing of these drivers.

Achieving a robust balance of several decommissioning drivers is a complex process. This decision making process becomes more critical as the size of the installation or the number of the installations being removed simultaneously increases, as the financial and socio-economic issues become more critical to the host state and the operating companies. This is represented in Figure 1 as a curve of gross tonnage of the installation or group of installations against the estimated decommissioning cost.

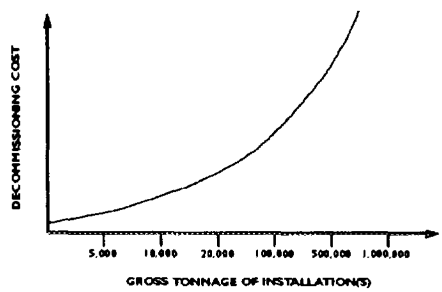

Figure 1: Decommissioning Cost Against Gross Tonnage of Installation(s) to be Removed

To date the offshore installations removed have been relatively small in size and usually only one installation at a time. Also due to the small size and location of these installations the optimal solution was total removal and the scope to optimise the decommissioning solution was minimal.

The decommissioning of large offshore installations is one of the few commercial races in which the oil companies would gladly like to be last. This point of view was confirmed when Shell UK attempted to remove the first large offshore installation in the North Sea, the Brent Spar. The Brent Spar is not only a large structure (13,800 tonnes and over 137 meters long) but it is unusual in that it is a concrete floating storage tank anchored by six mooring lines to the sea bed. Shell UK attempted to produce an optimum decommissioning solution and carried out numerous engineering, environmental and risk & safety evaluations. The result of these extensive evaluations was a Best Practicable Environmental Option (BPEO) which was the deep sea disposal of the Brent Spar. Shell UK then proceeded in accordance with the national, regional and international law and regulation to seek approval for deep sea disposal. Full approval was granted by all governments and international organisations. But even this rigorous process stumbled as it became clear that Shell UK had underestimated the reaction of some of the stakeholders, namely the public and the environmental lobby.

1.1 The Balance

It is difficult to ascertain exactly what Shell UK did wrong from a technical and legal point of view as they seemed to have followed the correct legal route and gathered all of the technical and scientific data to support their case. Possibly the only way the industry can learn from the Brent Spar experience is to develop a Decision Making and Evaluation (DME) process which encompasses the principal decommissioning drivers. This experience has also shown that in the North Sea region it is important to be sensitive to the and keep the public by keeping them informed on the decommissioning options and why one alternative may be preferred.

To find a balanced optimum solution one may start by trying to balance three drivers i.e. environmental issues, risk & safety and cost, as shown in Figures 2 (a) and 2 (b). The key to finding the optimum solution is the determination of the weighting factors. If all three drivers had the same weighting factor of 100 then the solution would be on the centroid, as shown in Figure 2 (a). If in case 2 the environment and the risk & safety were weighted 100 and the cost 50 than the solution in Figure 2 (b) would emerge.

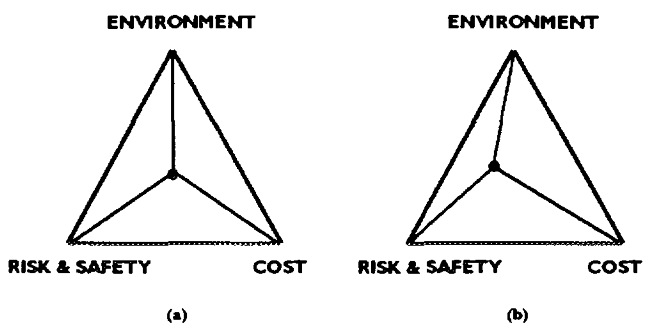

Figure 2: Finding a Balance Optimum Decommissioning Solution

If technology is applied to optimise the outcome then it is possible to produce a solution as shown in Figure 3. The area of solution is the triangular area just below the technology apex.

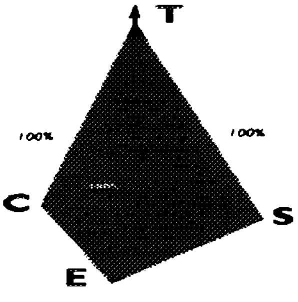

Figure 3: Convergence with Advancing Technol;ogy

A typical three stage screening and DME process to find an optimum decommissioning option is shown in Figure 4 (on the next page).

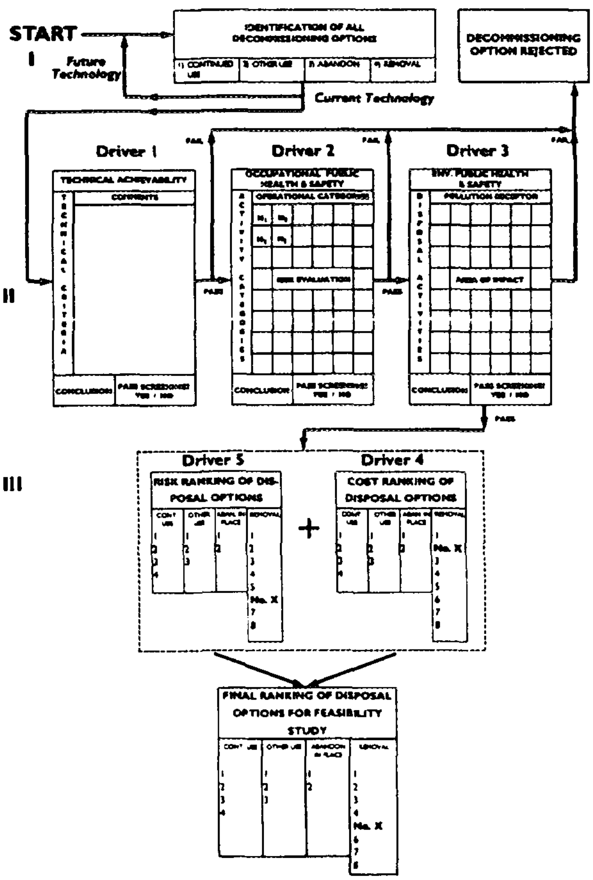

Figure 4: Selection of Decommissioning Option

In this example, five drivers are considered, technology, cost, risk, OHS and EPHS. Once this process is complete it is difficult to alter the weighting of the variables and to determine the effect of the outcome. To enable the rapid determination of the changing inter-relationship of more than three variables a complex DME methodology will be required.

1.2 Achieving An Optimum Multi-Driver Decommissioning Option

This DME process would encompass the weighting of each driver and the ability to alter one or more variables and then to examine the outcome. The process may consist of three main parts, as shown in Figure 5, the input data (technical, OHS, EPHS, legal, financial, socio-economic etc.), the decision making analysis package and the testing of the outcome or the measuring of the public perception.

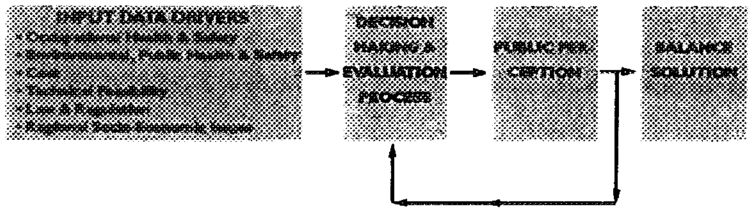

Figure 5: Mechanism for the Selection & Evaluation of Multi-Driver Decommissioning Option

The evaluation of the public perception is the most difficult part of this process and would require the identification of all of the stakeholders who were concerned with the selection of the decommissioning option.

A typical list of stakeholders are shown in Table 1, but this list may vary depending on the geographic location. The object of the DME process is to produced a balanced solution which has encompassed the views of all stake holders and a which has included and addressed the concerns of an *informed* public.

Media	Research Institutions
Communes & government	Oil Industry
EPA	Commercial Fishing
Department of Energy	Sport fishing
Department of Defence	Service Companies
Coastguard	Recycling Companies
Divers	Environmental
Shipping	Legal
Politicians	Insurance
NPD	Financial
Fish & Wildlife Service	Recreational Diving
The general public	International Communities
Tax Payers	Marine Constructors

Table 1: Possible Stakeholders in Decommissioning

2 Technological Challenges

The technical challenges have been divided into those applied to jacket installations, gravity based installations and pipelines.

2.1 Jacket Installations

All decommissioning categories may involve deconstruction activities. The methods and tools available for deconstruction can be divided into four groups:

- Lifting (crane vessels).
- Piece-small deconstruction.
- Toppling.
- Floatation.

The conventional method of removing offshore installations is by using crane vessels to lift the topsides in modules onto barges. Due to the extensive marine equipment required the cost of removing the topsides can easily match if not exceed the cost of installation of the same topsides (this has proven to be the case in the Gulf of Mexico).

The removal of the large steel jackets (in excess of 10,000 tonnes) with a crane vessel is more difficult as the jackets cannot be lifted safely in one piece. Hence to remove a large jacket, which was originally barge launched during installation, the jacket must be cut underwater into smaller sections. This is a complex, expensive and hither to untested technology. One alternative which is being investigated is the toppling of these large jackets onto the sea bed. Toppling of jackets in one section by remote cutting techniques is also a cost effective option and at the same time representing relatively lower risk to personnel.

Another method which is being considered for the removal of topside modules offshore is piece small removal. Piece-small methods for deconstruction of topsides, involving the use of hydraulic shears or other cutting devices and most importantly do not usually require an expensive marine spread including a crane vessel.

Due to operational risks and high cost, to date floatation methods are not found acceptable. New flotation methods, such as controlled variable buoyancy bags, are currently being developed which may reduce risks and cost. Further development of concepts like the C-barge and Pieter Schelte, which remove the topsides in one piece without crane vessels, the may offer the potential for lowering risks and costs of the deconstruction process.

There are several areas which require further consideration and development. These include:

- Identification of offshore and onshore disposal sites and disposal routes.
- Further engineering of toppling options and underwater explosive cutting methods.
- Further development of piece small option..
- Further assessment of Continued use, Other use and Abandon in place options.

- Assessment of the potential environmental benefits associated with the provision of a high relief solid substrate suitable for colonisation by epibenthic organisms, (artificial reefs).
- Identification of location, profile and physio-chemical characterisation of the drilling mud/cuttings heaps. Development of technology to remove the drill cuttings.
- Assessment of the interest of commercial fishermen in the utilisation of waters in the vicinity of a proposed offshore disposal site.

2.2 Gravity Based Installations.

The large Gravity Based Structures (GBS's) were designed to be refloated and either towed to shore for disposal or dumped in the deep sea. The breakout of these large structures will most likely be the most difficult technical part of this operation but the onshore breakup and disposal of up to one and a half million tonnes of reinforced concrete would be a daunting and high risk operation. It is most likely that these giant structures will remain in situ with the topsides removed and the shafts cut to achieve the regulatory 55 meters clearance at LAT.

The parts of the GBS which has been used to store oil will require cleaning. The issue of how clean is clean is being currently investigated in a number of studies. Two methods of removing the topsides seem feasible, lifting and piece small deconstruction.

If a GBS is to be refloated extensive engineering may be required, as all refloat options are associated with uncertainties regarding the structural/material integrity during the refloat operation. All further use in situ of the concrete structures are associated with high costs, due to continuing subsidence.

There are several areas to be considered for further development to enable the engineers and scientists to make more informed decisions :

- Corrosion monitoring of concrete materials.
- Identification of offshore and onshore disposal sites and possible routes.
- A technical study on the breakout and refloat of the GBS's.
- Development of more precise computer modeling techniques to predict the breakout from the seabed and refloat of the GBS's.
- Development of silent/slow explosive concrete breakers for underwater and onshore fragmentation.
- Development of water cannons using seawater to cut concrete structures in situ and toppling of the GBS's.
- Development of enabling technology for the cutting of the shafts.

2.3 Subsea Pipelines

Abandonment in Place of the interconnecting pipelines stands out as a low cost option. Two removal methods seem feasible; recovery by reverse lay from a lay barge, or sectioning on seafloor. The former is clearly the most cost effective of these options. Relocation of pipelines for continued use elsewhere may be possible, subject to confirmation of structural integrity.

It is recommended that certain issues will require further examination these include:

- Further examination of the methodology of removing the concrete coating for the disposal of the pipelines.
- Sectioning/recovery of the pipelines for possible reuse.
- Examination of the decay process for pipelines abandoned in place.
- Assessment of the residual liability of abandoning the pipelines in place.

3 Organisational

There are significant organisational issues created by the decommissioning of an offshore installation. Some of these are:

Mobilisation/Demobilisation
This includes transport of equipment and crew to quayside mobilisation site; transferring and securing of required equipment onboard the vessel; transiting to the site; anchoring and positioning; and upon completion of the offshore work, returning to quayside for removal of the equipment.

Deck (Topsides) Work
All above deck work including preparatory work; removal of topsides and transfer and securing to transport vessel.

Jacket/GBS Work
All Jacket/GBS work including, both above and below the water surface, including preparatory work; removal of jacket and transfer and securing to transport vessel. This includes all manned sub-sea work including manned submersibles and open water diving.

Internal buoyancy work (GBS only) involves increasing buoyancy by removing solid ballast and ballast water. The actions included are installation of pumps/ piping/ /instrumentation/hydraulics/solid ballast removal equipment by temporary modification works; and evacuation of solid ballast from compartments by e.g. air lifts and offloading into suitable vessels for transport and disposal onshore or offshore.

Transport of Structure
Transport to final destination site, either onshore dismantling and disposal sites or deep water offshore site or emplacement site. Vessel movement and handling (e.g. barges) within the project area and transit to and from the mobilisation site and other nearshore transfer sites and offshore or onshore disposal sites.

Transfer at Final Destination
Transfer from the transfer vessel to final destination site, either onshore dismantling and disposal sites or deep water offshore site or emplacement or toppling site. For deep water disposal site this can involve scuttling of structure and transport barge or launching of the structure. For onshore this can involve various methods including skidding and the use of crane vessels.

Onshore Dismantling and Disposal
Dismantling at receiving yard and transport to final disposal/reuse/recycling site. This includes exposure to radioactive material and other chemicals. This will involve extensive cutting and welding operations.

Offshore Disposal
This includes offshore deep water disposal, and toppling and emplacement in situ and disposal in a fjord.

In Table 2 below we can see that there are a number of possible final disposal sites. The organisational complexity is greatly increased if the installation is to be totally removed onshore as all of the material in the installation must be disposed of with a fully documented audit trail.

Table 2: Possible Final Disposal Sites
Offshore within the 500m safety zone of the platform, plus anchorage.
Offshore deep sea disposal site.
Offshore wider North Sea.
Coastal within the 12 mile limit. (Including Fjords)
Onshore.

4. Environmental

The environmental challenge during the decommissioning offshore installations is to carry out the operations in a prudent manner from a health, safety and environmental point of view. The environmental issues will deal with these issues from two different approaches namely Occupational Health and Safety (OHS) of the personnel involved in the decommissioning activities and the impacts on environmental and public health and safety (EPHS) as a result of the decommissioning activities.

If the decommissioning of offshore installations is examined from an OHS perspective, the optimum solution will be to render the installation hydrocarbon and chemical free and abandon the it in place. This option would entail the minimum overall worker exposure to hazards as minimal deconstruction would be carried out. This solution, however, may be in conflict with other users of the sea.

However from an EPHS perspective, the preferred solution, in the short term, would be to abandon the structure in place, following the removal or cleaning and stripping down to bare structural steel of the topsides modules. Associated disadvantages could include restrictions to other resource uses, such as commercial fisheries activities, the loss of steel for re-cycling, and the generation of debris following the natural decay of the structures.

Potential EPHS advantages could include a possible vertical artificial reef effect, and the relative reduction in potential environmental impacts associated with avoidance of disturbance of drill cuttings and mud piles, and other deconstruction, transport and final destination activities associated with other disposal options. However, to determine if this is a viable long term option, it will be necessary to carry out an energy balance, and to carry out a comparative assessment of the other feasible disposal options, including quantifying the potential environmental effects, and assessing their significance from an environmental, resource use and public perception perspective.

The environmental parameters (i.e. biological; physical and socio-economic) and the associated potential *types of impact* used in a typical evaluation are described in Table 3 below:

Environmental Parameter	**Type of Impact**
Physical Parameters: **Air quality**	Effects on air quality from onshore and offshore removal and final destination activities.
Water Quality	Effects on water quality from offshore or onshore removal and final destination activities, including effects associated with the physical presence of the structure.
Land/Seabed Effects	Effects on land or the seabed from the disturbance of sediment or soil, the release of contaminants or the physical presence of debris or structure.
Noise and Vibration	Effects of noise and vibration associated with offshore and onshore disposal activities on biological resources
Biological Parameters: **Biological Resources**	Effects on habitat, flora and fauna associated with a particular geographical area that is potentially affected by onshore or offshore activities.
Socio-Economic Parameters: **Public Nuisance/Amenity**	Including visual impact. a)passive effects such as those associated with noise, odor, smoke, dust and other disturbances, such as increases in heavy traffic, on local communities; b) recreational effects.
Commercial Land/Water Use	Effects potentially restricting other commercial activities such as commercial fisheries and navigation.

No matter which decommissioning option is chosen, a waste management strategy should be developed to classify and quantify residual materials and to establish potential final destination routes for both surplus and waste materials. The emphasis for the strategy should be optimisation of equipment by first examining reuse, then re-cycling , land fill and final incineration.

The disposal option selected will depend on the composition of the material and in generic terms, the options include:

Re-use - this could apply to items of equipment (e.g. pumps, compressors, separators, generators, cranes, portable equipment) some chemicals (e.g. refrigerants, Halon, un-used chemicals, bulks) or indeed the complete structure.

- Re-cycle - this could apply to any metallic materials (e.g. structural steel, iron ore ballast, copper wiring), waste oils and solvents.
- Landfill - this disposal route could apply to non hazardous materials such as materials removed from the accommodation; certain landfill sites are also licensed to accommodate hazardous materials, such as asbestos.
- Incineration - this disposal route could be used for disposing of hazardous materials, such as residual chemicals and materials containing PCBs.

Certain materials, such as LSA/NORM, will require specialist disposal and the use of a number of specialist treatment plants (either to neutralise or to dispose of materials).

For offshore and onshore final destinations, transport routes should be planned, as far as practicable, to minimise potential impacts in areas of high biological, recreational or commercial resource value. The anchoring of vessels should be carefully planned to minimise the disturbance of sediment and cuttings /drilling piles.

For both marine operations and for disposal options utilising explosive cutting, measures should be taken to mitigate the noise and vibration effects that could potentially detrimentally affect fish and mammals in the vicinity.

5. Conclusions

Due to the complexity of the inter relationships between the primary drivers one cannot separate the technological, organisational and environmental issues raised by the decommissioning of offshore installations. The optimal solution will be a compromise between all of the decommissioning drivers mentioned in the is paper.

To achieve this a decision making analysis system, encompassing the weighting of each driver and the ability to alter one or more variables, is required to test the outcome and measure the effect of public perception.

Each decommissioning solution is different even for similar installations at different locations. Hence the national and international law & regulation need to be flexible to facilitate a case-by-case evaluation and hence enable an optimum decommissioning solution to be achieved.

During the decommissioning operations carried out to date, the costs incurred have not been of a sufficient order of magnitude to enable the operators to develop an optimum solution. In most cases the socio-economic impact on the host state has not been sufficiently researched and hence no significant new technology has been employed to reduce the costs.

Identify and involve the stakeholders or parties concerned with the decommissioning of offshore installations. The commercial fishermen and the other users of the sea must be involved in discussion process.

Conclusions: Technical

The following technical issues also need to be addressed to optimise the removal of large installations or grouos of installations:

- Develop of more precise computer modeling techniques to predict the breakout from the seabed and refloat of the GBS's.
- Develop of silent/slow explosive concrete breakers for underwater and onshore fragmentation.
- Develop of explosive technology or other technology enable the cutting of the shafts underwater.
- Assessment of the potential environmental benefits associated with the provision of a high relief solid substrate suitable for colonisation by epibenthic organisms, (artificial reefs).
- Identification of offshore and onshore disposal sites and disposal routes.
- Further engineering of toppling options and underwater explosive cutting methods.
- Further development of piece small option.