FROM A CHINESE BUTTERFLY TO NAILS

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The Frigg Field
ABSTRACT

The Frigg Field, TOTAL’s giant natural gas field in the North Sea was permanently shut-in after 27 years of production. An excellent safety record, a unique reliability of over 99% and a recovery rate of 78% of the reserves (amounting to 192x10^9 SM^3 produced volumes), are some of the impressive results obtained during the life of the field.

The Frigg Field is one of the first major fields, about to complete a full life cycle. The aim of this paper therefore is to extract two of the - late life - main learning experiences, which hopefully are of interest for the industry today:

• Downsizing and restructuring of operations
• Decommissioning of the Frigg Field

Downsizing and restructuring of operations: This paper will give a detailed description of how some quite remarkable results were obtained through an optimisation project called FUTOP (Future Operations). The objective of this challenging project was to convert the Frigg and Heimdal fields from large gas producers to highly efficient, safe and reliable low level producers. An in-house developed RCM (Reliability Centred Maintenance) methodology allowed a 41% reduction of the preventive maintenance program. An in-depth analysis of the curative maintenance (break-down) history revealed a surprising result: Only approx. 13% of the repairs were of such a criticality, that immediate intervention by the operational crew was required. This fact allowed for a far more efficient campaign manning. A new and unique RCO (Reliability Centred Operations) concept and methodology was developed to address all activities apart from direct maintenance work. This resulted in an improved efficiency of the operations and rationalised responsibilities, thereby achieved a reduction in estimated man-hours of 26%. The overall OPEX reduction was 30% and up until the end of the prolonged field life a high safety standard was maintained and no change in production reliability or breakdown has been observed.

Decommissioning of the Frigg Field: The size and complexity of the decommissioning project for the removal of the Frigg facilities represent a greater challenge, than any previous offshore decommissioning project. The process of reaching approval of the recommended disposal arrangements took nearly five years starting in 1999, when the stakeholders were invited to comment the program for the environmental impact assessment. A constructive consultation process followed with Non-Governmental Organisations (NGOs), Norwegian and UK authorities, the Contracting Parties in the OSPAR Convention and finally by April 2004, the approval of the Frigg Field Cessation Plan had been obtained from both the Norwegian and UK authorities.

Great efforts were in particular made to investigate the feasibility and the corresponding uncertainties in a refloat operation of the three huge concrete substructures which had not been designed for removal. Comparative assessments of the possible disposal options were made addressing the technical feasibility, risk to personnel, impact on the environment and cost. The removal operations started in August 2005 and are expected to be completed in 2008, followed by further onshore disposal. The objective is to obtain less than 2% (weight) of removed material disposed of at a landfill.
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2. INTRODUCTION

The Frigg Field, TOTAL’s giant natural gas field in the North Sea, finally gave out on October 26, 2004 when the last well was permanently shut-in after 27 years of production. An excellent safety record, a unique reliability of over 99% and a recovery rate of 78% of the reserves (amounting to $192 \times 10^9$ SM$^3$ produced volumes), are some of the impressive results obtained during the life of the field.

The Frigg Field straddles the border line between UK and Norway 230 km northwest of Stavanger. The Frigg formation is of Lower Eocene age, with the upper part, located 2000m below MSL, constituting the hydrocarbon-bearing interval. The field had an area coverage of 100 km$^2$ and a gas column thickness of 160 m. The shape of the field led to it being known as “The Chinese Butterfly”. The field was originally developed with 5 platforms and a flare tower. There were two Drilling & Production platforms each with 24 wells; two Treatment & Compression platforms and one Quarters Platform. Produced gas was exported to the shore terminal at St. Fergus, Scotland, via two 32” pipelines. During the years of plateau production (1978-1987) the Frigg Field provided one third of the UK’s natural gas demand, with a yearly production of $16.5 \times 10^9$ Sm$^3$ and a peak daily production rate of $80 \times 10^6$ SM$^3$/day. Ownership (reserves) of the field was split between: TOTAL E&P (NORGE & UK): 76.97%, Norsk Hydro: 19.99%, Statoil: 3.01%.

As one of the first major discoveries on the Norwegian Continental Shelf, the field has a proven record – not only as an initial pioneer – but also as an innovative developer of technology, satellite fields, change management, tail end production and cessation.

It is claimed, that only the small oil companies can manage tail-end production efficiently. On Frigg both the organisation and the operational philosophy was radically changed in 1997 resulting in a prolonged field life, an economical break-even rate of less than $1 \times 10^6$ SM$^3$/day with a technical cost of 4$/boe. Considering a 27 year old field with 4 active platforms and a treatment capacity, which could receive a 4-5 times higher production rate without an increase in operating expenses, we have proved that the Majors can be in the absolute frontline.

The Frigg Field is one of the first major fields, about to complete a full life cycle, and as such the history book contains a valuable treasure of innovations, experiences and sustainability ranging from geo-science and pure technology, through field optimisation, tail-end production and cessation.

Some Frigg experiences – although important developments at the time – have become standard or have been further developed. The aim of this paper therefore is to extract two of the main learning experiences, which still have value and are hopefully of interest for the industry today:

- **Downsizing and restructuring of operations**
- **Decommissioning of the Frigg Field**
3. SAFETY

A field life of 27 years in a harsh environment naturally imposes major safety challenges especially in respect to the tail-end production phase. These include aspects such as: Integrity of process equipment & structures, hydrocarbon leaks, cost & resource cutting to maintain profitability, reorganisations, de-manning, motivation, competence, culture etc.

3.1 Condition Assessment:

A condition and risk based inspection system, which was prepared in-house and subsequently developed into an on-line web based system with automatic updated trends, proved surprisingly accurate and predictive.

Classic inspection systems for platform/plants were established through static programs, without consideration of present condition. In 1995, after close to 20 years operation of the Frigg Field, history and knowledge gained related to platform behaviour was used to establish a new Inspection Philosophy. An evaluation of the complete concept around Inspection Management was carried out, with the aim to optimise the administration of programs and data, focus on the relevant items and increase the efficiency.

Development of a method to individually evaluate the various inspection systems was introduced. Each inspection system was classified in pre-defined inspection categories, ranged according to the potential risk involved if failure occurs. It was based on condition and qualitative risk evaluation of each operational system.

A relation between present system condition, expected degradation over time for each inspection category was established. This was used to calculate the interval to the next inspection. With a differentiation in inspection intervals where present condition is taken into account, a more optimised and efficient inspection programme was obtained.

A total of 170 inspection systems were evaluated and more than 670 routines generated. Each routine describes item and type of inspection and gives relevant information as attachments. In order to handle the amount of routines and increasing data, a database was needed.

The Condition and Risk based Inspection System, CRIS, was designed based on Oracle and was integrated in the data network both on- and off-shore. This was later developed into a web-based improved version. It contained the full loop from the evaluation process, through routines, programs (with attachment of system descriptions, procedures, etc., reporting and history to the updating of the new program.

For the last phase of Frigg the system was instrumental for a safe and economical operation of the field.

After 9 years of operation with the Inspection system, the following advantages have been obtained:
• Reduction in cost and resources
• Targeting the resources to the critical areas
• Easy identification and follow up of inspection findings
• Completing the experience feedback loop
• Easy global reporting and trend analysis

3.2 Competence and culture

In today’s industry a lot of resources are used to develop a good safety culture. The importance of this is of course undis disputable, but culture is a phenomenon which changes with both time and society and, as such, is a moving target which is hard to manage in an optimal way. On the other hand, the fundamentals of technical process safety competence have not changed much in the last 20 years and are therefore easier to manage, with resulting significant improvement in safety. Technical training and special intervention procedures combined with a strong management focus on even the smallest gas leaks resulted in no reportable (>0.1kg/s) gas leaks on Frigg during the last 6 years of production. Our experience has therefore been to favour technical safety training and to “spice it up” with cultural programmes.

4. DOWNSIZING AND RESTRUCTURING OF OPERATIONS

Due to the strong acting aquifer present in the Frigg reservoir, the rapid water encroachment led to successive stop of production from 24 wells up to in 1990 and thus a drastic reduction in the daily gas production level (from 20 to 6,5 x10^6 SM^3/day) with a continuous decline during the nineties. In order to prolong the Frigg gas production and benefit from the investments made in the installations, the Frigg Partners agreed to develop the Frigg Central Complex to a centre for treatment of oil and gas from fields in the area. A new Participation Agreement was worked out, including an operating cost allocation procedure to ease introduction of new users on the Frigg Central Complex.

4.1 Satellite & Marginal field developments

Everyone agrees, that it is important to develop satellite/marginal fields before the main reservoir is depleted to allow for cost-efficient processing, use of export infrastructure and to avoid stranded reserves. There is however a critical time period for development to allow for optimised unit costs, sufficient funds/resources and a will to acknowledge these fields not only based on economical reserves, but as important technology drivers for the future. The development of Lille Frigg (the first HP/HT sub sea field on the NCS) and Frøy, with start up in 1994 and 1995, should be the start of a new period in the life of Frigg, and allow for a longer Frigg tail gas production as a major part of the operating cost was covered by third party users. The satellites
Odin (operated by Esso) and North East Frigg (the first remotely controlled semi-sub sea field on the NCS) were stopped in 1993/94, after 10 year production period. East Frigg (the first diver less modular based sub sea field on the NCS) came into production from 1988, and was stopped in 1997. The Frøy and Lille Frigg fields had lower reserves than estimated, and were stopped in 1999 for Lille Frigg and 2001 for Frøy. All the operating cost had after 2001 to be covered by the Frigg gas production. Never the less major cost reducing initiatives were required to maintain high profitability and to prolong the field life. In the period 1993-1997 a number of cost reducing projects were performed:

**RED OPEX Projects (1993-95)**
Annual savings of 13 Million Euros: This initiative consisted of a total of twenty six projects involving over 80 employees. Improved work methods having a cost benefit were identified using a structured problem solving technique focused on work processes. The broad employee participation and the short decision loops, from initial proposals to implementation, were major contributors to the success of the projects.

### 4.2 The FUTOP Project

The object of this unusual and challenging project was to convert the Frigg and Heimdal Fields from large offshore gas producers, to highly efficient, safe and reliable low level producers during the decline phase of the field life.

The traditional approach to cost cutting exercises has been to perform a number of more or less independent projects, addressing the various offshore operational cost drivers. However, such an approach has often resulted in inconsistencies and less than optimal savings. One of the main objectives of the FUTOP (Future Operations) Project was therefore to achieve a balanced, optimised solution, centred upon a “total concept” approach. All the various studies, models, analyses and evaluations were therefore undertaken as interactive elements within the overall project. The Project has been executed in two steps:

- **Phase I**: Maintenance optimisation and preparation of new maintenance routines.
- **Phase II**: Operational activity assessment, organisational development and implementation.

In order to identify the actual needs for change and measure the effect of the proposed results it was necessary to prepare maintenance and production cost models, production profiles forecast models and shutdown loss models as basis for the criticality evaluations to be made later as part of the maintenance and operational studies. Economical models were prepared for calculation of man-hour cost figures and activity cost estimation for input to cost-benefit assessments.

### 4.3 Preventive maintenance

The first frame condition we challenged was the preventive maintenance. Just a few years back we did a major baseline survey to optimise the PM so the general opinion was that we could only sub-optimise.
But let’s take a look at where all these preventive maintenance programs come from. First of all they come from the vendors and of course they inject so much fat in their programs that their equipment will function as good as possible. But - at the prize of the operator.

Then the maintenance personnel set up and perform the programs. But who are they? Well, they are somebody that never gets credit where everything runs smoothly and when things brake down they are always to blame! So it’s obvious that they like some fat in the programs as well.

However our main objective is not to maintain or produce or to please the vendors but to “perform sufficient operations to obtain a given production regularity”.

The key words are “sufficient operations” where sufficient means “no more - no less” and “operations” that the trades have a common objective (teamwork).

4.4 RCM methodology and working process

The methodology developed to optimise the maintenance activities is based on the theories of Reliability Centred Maintenance (RCM), often also denoted as Risk Based Maintenance (RBM). In principle, this implies that the maintenance strategy is established on the basis of a systematic evaluation of failure modes and their effect on safety, production loss and asset cost. In addition, the actual risk evaluations and recommended maintenance strategies have taken into account the operational experience gained on Frigg and Heimdal through many years of operation.

By maintenance strategy is meant the principles of maintenance i.e. regular testing/inspection, condition monitoring, 1st degree maintenance, preventive or corrective maintenance. The methodology has been used to arrive at an optimum maintenance strategy based on a criticality assessment of systems, equipment and components taking into account the probability of possible failure and all associated consequences (i.e. risk). The criticality assessment is performed in work sessions with participation from all maintenance and production trades, including offshore and onshore personnel and the risk evaluations and conclusions have been documented in the RCM database.

Many operating companies had tried to introduce this concept, but only with limited success. The main reason for this has been that in most cases the concept and the RCM analyses have been developed by onshore Methods and Development Engineers, and the results forced upon the offshore organisation afterwards. This would have been in contrast to our agreed success factors. Therefore, we decided to bring selected offshore technicians and supervisors to the RCM team as the backbone of the project, supported by method engineers and trade professionals from the onshore organisation.

The methodology and the working process were tailor-made by the project group through selected pilot cases. It has been equally important to carry out the assessment on an appropriate level of detail in order to take the results from the RCM analysis into practical activities in the maintenance program. This would have been difficult and very time consuming without active participation by maintenance personnel in the RCM team. The RCM methodology is developed for selection of maintenance strategy to cope with the various failure modes, but due to the participation of experienced offshore
technicians it was possible to go a step further in proposing changes to the current maintenance program on basis of the RCM evaluations which made the implementation easier. Another success factor which became important, was the ability to follow-up the consequences of a reduced PM program, not only technically, but also by making the necessary adjustments of the organisation.

In the following the RMC methodology and the working principles have been briefly described

### 4.5 RCM analysis - Criticality Assessment

The RCM evaluations are carried out in work sessions (meetings) according to the principles shown in Figure 1. It has been important to the working process that the "optimal" maintenance strategy has been obtained on basis of the risk evaluations and thereby emphasising the actual needs of performing preventive maintenance. The optimal strategy has been established without discussing the efficiency of the current practice. However, prior to concluding the recommended strategy, the optimal strategy has been verified against current practice and any specific and relevant rules or regulations to ensure that important aspects have not been left out.

The risk evaluation has considered the following parameters:

- Safety for personnel, external environment and the working environment.
- Production loss.
- Potential follow (damage) cost.
- Regulations and company requirements which require that certain maintenance procedures are followed.
- Specific dominating problem areas and extensive corrective maintenance activities related to the equipment.

In principle, the criticality assessment on equipment level is carried out in a similar way to the system level assessment, except that when the RCM evaluations have been performed on equipment level, focus has been on sub-functions and the loss of these functions (failure modes), failure characteristics, possible pre-warnings or failure indications, consequences of the failure modes, possible follow cost, and the actual effect of the current maintenance taken place on the specific items or sub-function.

Each failure mode or loss of a sub-function, is assessed according to how critical the loss is assumed to be with respect to safety for personnel/the environment, production loss or follow on cost. For this purpose a set of risk matrices have been developed. The risk categories range from:

- **VL:** Very Low risk/insignificant risk.
- **L:** Low risk.
- **M:** Medium risk.
The project group has assessed both the consequences and the frequency of occurrence according to the standardised risk matrices, which ensure a consistent and well documented approach to the risk assessments. The risk classification has been performed for each failure mode, and the results have been applied when going through a decision logic to finally arrive at the preferred (optimal) maintenance strategy, see Figure 1. The decision logic has different outcome if the risk is Very Low or Low compared to if it is Medium, High or Very High. In this manner the criticality assessment directly affect the maintenance strategy selected.

### 4.6 Decision logic - new maintenance strategy

In order to make conclusions on basis of parameters which are not directly compatible, a general decision logic is developed, see Figure 1. The decision logic serves three important purposes:

- Ensure a systematic evaluation of the need for preventive maintenance activities (PM).
- Ensure consistency of the evaluation between the different platforms and systems.
- Simplify the documentation of the conclusions reached.

![Decision Logic A](image)

Figure 1: Decision logic for production or utility systems

**Legend:**
- **Y:** Yes
- **N:** No
- **A:** Assessment
- **N:** Not Assessed
- **Y:** Yes
- **N:** No
- **A:** Assessment
- **N:** Not Assessed

**Decision Logic A**

<table>
<thead>
<tr>
<th>Cause, Criticality and Cost Efficiency</th>
<th>1st Degree Maintenance</th>
<th>Failure Detectability</th>
<th>Failure Characteristic</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can failure cause be identified and is preventative maintenance cost effective?</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Implement preventive - oper. conditions</td>
</tr>
<tr>
<td>Is failure consequence low for safety (incl. environment)?</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Regular testing/ inspections</td>
</tr>
<tr>
<td>Is failure consequence low for production or follow cost?</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Time-based maintenance, running hour or calendar-based (PM)</td>
</tr>
<tr>
<td>Is 1st degree maintenance applicable and effective?</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Implement modification</td>
</tr>
<tr>
<td>Does 1st degree maintenance fulfill requirements for preventive maintenance?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Condition Based Maintenance</td>
</tr>
<tr>
<td>Is hidden failure detectable by:</td>
<td></td>
<td></td>
<td></td>
<td>1st Degree Maintenance</td>
</tr>
<tr>
<td>a. Operator Technician during normal duties?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Corrective Maintenance</td>
</tr>
<tr>
<td>b. Condition monitoring methods?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Corrective Maintenance</td>
</tr>
<tr>
<td>c. Analysis of process data?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Corrective Maintenance</td>
</tr>
</tbody>
</table>
In principle, the decision logic advises the preferred maintenance strategy on basis of the criticality assessment, detectability of failure and the failure characteristics. It is normally applied on either system, equipment or sub-function level to assess the criticality of loss of the sub-function (or equipment), ref. selection of systems.

A separate set of principles for evaluation of safety systems and safety functions were developed:

- The present safety level is acceptable on all installations.
- The reliability (availability) of existing essential safety systems should be maintained.
- The project assumes that the existing safety systems are designed in accordance with applicable rules and regulations and maintained adequately. This implies that Frigg & Heimdal - Future Operations will not question the need and the efficiency of the safety systems.
- The minimum safety standard defined by the design basis should be maintained, e.g. if a safety system is designed according to API, the system should also be maintained adequately to comply with the intention of the defined standard.
- Modification of existing PM routines and test intervals should be implemented only if:
  a) The new routines improve or at least maintain the overall safety level.
  b) The routines change focus from reliable components towards components which are experienced to be less reliable thus obtaining an equivalent standard.

Based on the principles above, a separate decision logic for optimisation of the maintenance work on safety systems and safety devices has been developed. Typical recommendations might be:

- Give more priority to the most unreliable components.
- Adjusting intervals based on experienced failures and statistical methods.
- Utilising that safety equipment can be tested functionally during operational related shutdowns.
- Better co-ordination between the trades and departments.

If the particular failure mode addressed did not have any impact on the safety function, the original decision logic shown in Figure 1 was applied. Similar, if a sub-tag of ordinary equipment performs a dedicated safety function the decision logic for safety systems were applied.

Results
The final result of the preventive maintenance optimisation work was a reduction of 41% of the preventive maintenance hours. In the seven years of production after the implementation of the new maintenance program, no change in production reliability or increase in curative (break-down) maintenance has been observed. We believe the industry has a large cost saving potential within this domain.
4.7 Corrective maintenance

Corrective maintenance is a term used to describe the activities required to repair or replace equipment offshore that has broken down or has been identified by personnel offshore as in eminent need of repair or replacement.

As opposed to preventive maintenance activities, the need for corrective action or the repairs will vary randomly during the years. It is by nature impossible to plan “what to do” and “when to do” the corrective actions before the failures actually have occurred. The contingency level for execution of repair actions will affect the production regularity as the downtime of the equipment depends on the ability to mobilise competent personnel, tools and spare parts. Therefore, the corrective maintenance strategies have to consider:

- Prioritisation of repair actions.
- Manning and competence requirements.
- Planning and execution of repair work.
- Co-ordination with other activities - especially production.
- Organisation of the repair teams.
- Availability of spare parts.

The overall objective of this project activity was to optimise corrective maintenance activities from an economical point of view, i.e. balance the level of contingency for repair with the expected loss due to production shutdowns and further improve the efficiency and the quality of the corrective maintenance work.

Previously the majority of the corrective maintenance work offshore was classified as “urgent” and to a large degree performed by the permanent offshore organisation. This makes it very difficult to plan corrective maintenance activities and allocate the necessary resources. A better way of prioritising the tasks was required. Once the tasks are prioritised it is also possible to evaluate the possibility for improving the efficiency of non-urgent tasks; to perform them at opportune times with optimum technical competence and manning.

4.8 Review of historical corrective maintenance records

In order to see the potential for improving the corrective maintenance activities, a review of the existing corrective maintenance records in was performed for Frigg and Heimdal, and the different activities were classified according to criticality and need for response.

This review was based on a printout of the corrective maintenance records for the last five years. Each failure resulted in a repair action, was classified according to the type, the repair time and the technical discipline contribution to the repair. This was done to be able to evaluate the possibility for having
different repair and manning strategies. The classification was performed by experienced personnel making a subjective evaluation of each of the failures recorded in the database and placing the failure in one of several categories.

The "types of failure" were classified into six main categories:

1. Critical failure of non-redundant equipment (shutdown of process).
2. Critical failure on redundant equipment (shutdown of equipment)
3. Failures with dominating safety implications or severe process control/metering consequences.
4. Minor failures or house-keeping actions.
5. Non-critical production disturbances on non-redundant equipment.
6. Non-critical production disturbance on redundant equipment.

The critical failures and the failures with dominating safety implications were further classified into the duration of time needed for repairing the failure.

The review and the classification of corrective actions was co-ordinated with the production availability analyses (the RAM analyses), and the need for field specific failure data for modelling of the Frigg/Frøy and Heimdal production availability.

The surprising results from the review of the maintenance records show that 85% to 90% of the corrective maintenance activities have sufficient time available to improve the planning of the activities and to gather the optimal resources. In other words only 10-15% of the failures critical to safety and production regularity required immediate repair of the permanent offshore crew. The remaining repairs could be performed by a campaign team. Based on these findings the basis for a complete new organisational model was emerging allowing to decrease the permanent manning offshore and allow for a much more efficient planning/logistics of repairs by the campaign team. The main tasks of the two teams were defined as:

- Operational Team: Production tasks and immediate and short duration repairs as well as 1st degree maintenance
- Campaign team: All other repairs and preventive maintenance.

With this concept it also became interesting to assess the potential of organising the operational teams as multi-task teams.
4.9 New repair strategy

Based on the economical models developed, the production shutdown cost estimates and the production availability models (RAM studies) the production and repair strategies have been developed to provide the offshore organisation with guidelines for prioritising the production and selecting which team to perform the repairs.

4.10 Operational activity analyses - RCO methodology and working principles

The methodology, which was developed by the project team to optimise the operational and administrative activities is based on the principles of Reliability Centred Maintenance (RCM). Therefore, the methodology developed for the purpose of the FUTOP project has been denoted Reliability Centred Operations (RCO). In principle, this implies that the operational activities are established on the basis of a systematic evaluation of the operational and 1st. degree activities and their effect on:

- Safety for personnel and the environment and work environment.
- Production loss.
- Operational expenses (OPEX).
- Work environment

In this context OPEX evaluations include work efficiency and work performance quality.

The RCO methodology have been used to arrive at an optimal operational strategy and management of the daily work activities, 1st degree maintenance and management / administrative functions based on criticality assessments of all operational - and control activities, as well as administrative functions. Further, the manpower requirement for conducting the work has been estimated for all professions, both for the current situation and for the recommended future operations. An extensive data and information gathering exercise took place offshore to prepare a basis for the RCO evaluations. The criticality assessment has been performed in work sessions with participation from production and the maintenance trades. As for the RCM sessions the cost-benefit evaluations and conclusions have been documented in the tailor-made RCO database.

The following working principles are applied for the RCO analysis of the regular activities carried out in connection with daily operation of the platforms:

1. The Frigg Field has been divided into Main Functions, which define typical process streams or utility functions. The Main Functions were originally defined entirely for the purpose of this study, but they describe suitable operational entities and have shown to be useful for organisation of the actual offshore operations. Each Main Function constitutes, in principle, of a set of defined maintenance systems, and the connection between the operational
activities and the maintenance activities was then established.

2. Current operational activities are identified and described including planning-, reporting requirements and reference to operational procedures. Further, expected man-hours are estimated for the operational activities performed on the Main Function. All defined Main Functions are subject to the RCO analysis. The activities are grouped into the following operational conditions:
   - Normal operations.
   - Planned shutdowns and deviations.
   - Un-planned shutdown situations.
A complete list of relevant operational standard activities has been established. For each standard activity the influence on safety for personnel and the environment/work environment, production regularity and cost (OPEX) were estimated by the project team in the RCO.

3. Based on operating experience, authority and internal requirements, the risk evaluation and the agreed decision logic, it is decided whether the activity, or an alternative (modified) activity, should be carried out in the future. Similar to the RCM evaluations, the recommended solutions have been verified against current practice to ensure completeness and consistency of the evaluations made.

4. The recommended activities have been described, responsible positions have been assigned, the need for planning, control, technical documentation, additional support/co-ordination, reporting functions, and the human resources (man-hours and competence) required to perform the actual work tasks have been defined. Recommendation for development of future performance indicator have been made for follow-up of particular activities.

4.11 Decision logic - new operational principles

Criticality matrices have been applied to classify the risk associated with possible consequences of inadequate performance or disregarding operational or administrative activities. A standard questionnaire/decision logic have been developed to ensure consistent evaluations throughout the project and to document the argument for selection of specific operational and administrative activities. The decision logic is shown in Figure 2. Based on the criticality assessment and the decision logic, the recommended strategies have been arrived upon.
Experienced personnel representing all trades have been central in development of the methodology as well as the performance of the actual RCO evaluations. The same people did also participate in the maintenance optimisation work. The aim of this was to ensure:

- “Hands on” knowledge and experience.
• Ownership of the work from the organisation.
• Acceptance of conclusions.
• Compliance and co-ordination of operational and maintenance tasks.

and to follow the course of a learning organisation.

The work has effectively been a bottom up process founded on the same principles and criteria as the maintenance strategy (RCM) evaluations.

Figure 2: Decision logic for operational and administration activities

Results
The outcome of the operational study is a tremendous detailed description of the operational activities including administrative tasks and the management principles applied on Frigg prior to the FUTOP project. Any single activity have been evaluated from a safety and operational point of view, and improvement of technical as well as administrative issues have been recommended with the aim of running the platforms more efficiently without compromising safety and the production regularity.

The overall result was a reduction in man-hours for operational activities of 28%. In addition, the RCO evaluation process have contributed significantly to the development of the new organisation and the evolution of the principles for co-operation between the trade professionals which very much have
been an iterative process in-between the RCO team members and between the RCO team and the organisation development task run by Fields Operations / FUTOP management.

Through the RCO logic which request details, not only about technical operational issues, but also about administration and management of the activities, the RCO team was forced to decide on organisation of all operational activities on a level of detail reflecting individual positions offshore. This is beyond the level of the management principles shown on organisations charts and in company management documents, but anyhow necessary for development and implementation of the new daily routines and practicalities required to keep the operations going.

4.12 Organisational development

Based on the described studies, risk assessments, models and evaluations all activities on Frigg down to a very detailed level had been mapped both in existing and optimised mode. Although the new organisation was slowly emerging through the project phase (at the end of the day all optimisation projects are organisational!), the final design had to tie all the results together. Both for the final design and the actual implementation of the new organisation it was a great advantage to have conducted the project as an in-house project with the core team members being the offshore technicians and supervisory personnel. A close and constructive co-operation with the unions was established based on the fact, that either we perform a drastic change operation or the field will be shut down.

Finalising the iteration between the quantitative availability studies (RAM) and the new optimised maintenance and operational strategies resulting in a reduction of man-hours of:

- Preventive maintenance: 41%
- Curative maintenance: 15%
- Operational activities: 26%

the total man-hours needed to run the field was defined for each Main Function on the platforms. The structure of the organisational model became a flat, multi-skilled, team based organisation with a high degree of individual responsibility. The various teams (each incl. process, electro, automation, mechanical) were each responsible for a number of Main Functions and each team member trade responsible for the various equipment (e.g. if a failure was mechanical dominant, the mechanic in the team was the boss of the repair incl. planning, spare parts, resources and execution). This excluded the first line supervisors from the old organisation and gave the technicians a very positively received lift in responsibility.

After the final optimisation the number of positions on Frigg was reduced with 24%.
4.13 Overall results – Main lessons learnt

The overall results of the FUTOP project were an annual saving of 30% and a four year prolongation of the production period. Up until the end of the field life a high safety standard was maintained and no change in production reliability or breakdowns has been observed.

Some of the main lessons learnt for a project like this are as follows:

- Any optimisation or de-manning project will naturally encounter defensive and counteracting reactions. Being transparent, open and involving from the start is a must, so we defined some critical success words/factors:
  - **Understanding**: By extensive and honest information – and discussions about the present and future situation – and the consequences
  - **Acceptance**: By participation in a common development towards solutions
  - **Confidence**: By showing, that what we say is what we do
  - **Competence**: By choosing the personnel for the various change projects from competence groups closest to the activity in questions.

The challenge is to get under the skin of the words, so they actually mean something - not just dinner speeches!

- Run it as a project – never underestimate the complexity. Coordinate all change projects in the company in the same period. Turn every stone while you are at it – people gets tired of constant change.
- Document your base and your recommended changes very detailed
- Use your technicians actively – they have more expertise than we engineers are willing to admit!
- Don’t implement before you are absolutely ready and then do it quick & dirty
- Keep a dedicated person for some time (we used a year!) after the implementation to ensure the organisation don’t return to old habits.
- Be ambitious – challenge the limits and they will move! Don’t define absolute and quantitative goals in the beginning - then you immediately will be in a negotiation position, which will limit you.

5. DECOMMISSIONING OF THE FRIGG FIELD

The size and complexity of the decommissioning project for the Frigg facilities represents a greater challenge than any previous offshore decommissioning project. The process of reaching approval of the recommended disposal arrangements took nearly five years starting in 1999, when the stakeholders were invited to comment the program for the environmental impact assessment. A constructive consultation process followed with the Norwegian and UK authorities, Non-Governmental
Organisations (NGOs), the Contracting Parties in the OSPAR Convention and finally in April 2004 approval of the Frigg Field Cessation Plan was obtained from both the Norwegian and UK authorities.

The Frigg Field, operated by TOTAL E&P NORGE AS, straddles the median line between Norway and the UK with installations in both sectors. A common approach to disposal was therefore adopted for both the Norwegian and UK facilities. Great efforts were made to investigate the feasibility of re-floating the three huge concrete substructures which had not been designed for removal. Comparative assessments of disposal options were made addressing the technical feasibility, risk to personnel, impact on the environment and cost. Independent experts were engaged to review the studies carried out. A peer review of the environmental impact assessment was also conducted.

The recommended disposal arrangements for each platform and the pipelines, cables and drill cuttings were then based on an overall judgement of both the factual aspects and the wider issues involved. The views of stakeholders were important in the decision making process. Compliance with OSPAR Decision 98/3 was main reference in addition to the Norwegian and UK legislation.

The approved disposal arrangements for the Frigg Field facilities are:

**Complete removal for onshore disposal:**
- Five topside facilities, total weight: 45,100 tonnes
- Three steel substructures (jackets), total weight: 20,000 tonnes
- Infield pipelines and cables between platforms

**Leave in place:**
- Three concrete substructures, after removing external steel works. Navigation aids will be installed on each substructure. Total weight: 809,000 tonnes.
- Drill cutting accumulations (max. 20 cm thick).

After the basic engineering was completed, five consortiums were selected in 2003 for the FEED preparation for the offshore removal and onshore disposal of the five topsides and three steel substructures on Frigg. Three consortia proposed normal heavy lifting methods, while two proposed “single lift” solutions. After the FEED and submission of offers, Aker Kvaerner Offshore Partner AS was awarded the contract in alliance with Saipem. The topsides will be removed either module by module by heavy lifting (reverse installation) or “piece small” (cut up by excavators located on the platform). The jackets will be re-floated with means of buoyancy tanks fixed to the jacket leg and then towed to shore for disposal.

The offshore removal and onshore disposal of the topside facilities on MCP-01, operated by TOTAL E&P UK PLC, will be integrated into the Frigg Cessation Project. Significant synergy effects are expected from such collaboration.
The offshore removal operations started on Frigg in August 2005 and are expected to be completed in 2008. The onshore disposal is expected to be completed a few years later. The objective is to recycle as much of the equipment and materials as practicable with less than 2% (weight) of removed material disposed on a landfill.

5.1 Overall Approach to Decommissioning

The OSPAR Commission meeting in Sintra in 1998 determined that there should be a “presumption for removal” of all redundant and decommissioned platforms in the North East Atlantic area, which includes the North Sea. This presumption led to the requirement that structures should be removed irrespective of any comparison of the environmental impact profile for removal with the environmental impact profiles of other alternatives. Derogations may however be sought in the case of severely damaged structures, concrete substructures or footing of large steel jackets (weighing more that 10,000 tonnes).

For each of the components to be decommissioned at Frigg the following sequential process has been followed to determine the recommended arrangements according to the “waste hierarchy” which values reuse above recycling and disposal onshore above disposal at sea.

- Evaluation of the possibility of reusing all or parts of the offshore facilities either in their current location or at another site
- Evaluation of the possibility of recycling all, or parts, of the offshore facilities
- Evaluation of the possibility of disposal onshore
- Evaluation of the possibility of disposal at sea

Studies and assessments have been conducted by many companies having specialist knowledge in the relevant field. The companies involved in the original design and construction of the platforms have been extensively used in this evaluation work. These companies have unique knowledge of the Frigg Field structures and have been responsible for considering how they might be removed, or disposed.

An extensive process of verification of the study findings has been conducted by leading independent experts from Norway, UK, Holland, Germany, Denmark, Switzerland and France. Seminars and workshops have been held to bring these experts together to the review the studies and ensure that both the input data, and the conclusions drawn from the work, were valid.

5.2 Possible Continued Use of the Frigg Facilities

A significant investment has been made in exploration in the Frigg area seeking hydrocarbon reservoirs that could be developed using the Frigg Field facilities. At present there are no other known reservoirs in the area that can be economically developed from Frigg.
Studies have also been undertaken which conclude that it is not economically attractive to use one or more of the Frigg Field platforms purely as an export centre to connect into the Frigg Field Transportation System pipelines. Technology today allows the direct subsea tie-in of pipelines to the Frigg export pipelines without the need for a platform. The use of the Frigg facilities as a processing centre is also found not to be viable.

A number of possible non oil and gas uses for the platforms have been evaluated including; artificial reefs; wind-generators; or emission free gas fired power plants. The feasibility of many of the options is technically uncertain and none of the arrangements are judged to be economically viable.

No potential reuse application has been identified for the three Frigg Field steel substructures at another location. The three Frigg Field concrete substructures have some potential for reuse at another location, if it were possible to refloat and relocate them without undue technical risk or risk to personnel.

There may be possibilities for the reuse of some of the topside equipment although much of it is rather old. TOTAL E&P NORGE AS will continue to actively pursue these possibilities.

5.3 Assessment of Disposal Alternatives

In the absence of any viable reuse potential for the Frigg Field facilities, evaluations and comparative assessments have been undertaken to determine how the facilities can be decommissioned.

In accordance with Norwegian and UK regulations, and OSPAR Decision 98/3, full removal and onshore disposal has been the only disposal option considered for the topsides and steel substructures. For these elements an evaluation of feasible methods for removal and onshore disposal has been undertaken. The cost and risks associated with this work have also been estimated. Full removal and onshore disposal has been the first option considered for the three concrete substructures. However, due to the complexity and uncertainties associated with the removal of these substructures, that were not specifically designed for such an operation, other disposal alternatives have also been considered, as provided for in OSPAR Decision 98/3. In the case of the concrete substructures, the infield pipelines/cables and the drill cuttings, a comparative assessment of different disposal alternatives has therefore been undertaken. Figure 3 below shows the various evaluations and comparative assessments undertaken for the Frigg Field facilities. For each of the alternatives, aspects such as technical feasibility, risk to personnel, cost and impact on the environment and society have been considered.
### Evaluation of Disposal Methods

<table>
<thead>
<tr>
<th>Steel Platform</th>
<th>Alternative A</th>
<th>Removal and onshore disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topsides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OP, DP2</td>
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<table>
<thead>
<tr>
<th>Steel Platform</th>
<th>Alternative A</th>
<th>Removal and onshore disposal</th>
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</thead>
<tbody>
<tr>
<td>Substructures</td>
<td></td>
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<tr>
<td>OP, DP2, DP1</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Concrete Platform</th>
<th>Alternative A</th>
<th>Removal and onshore disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topsides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCP2, CDP1, TP1</td>
<td></td>
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</tr>
</tbody>
</table>

### Comparative Assessment of Disposal Alternatives

<table>
<thead>
<tr>
<th>Concrete Platform</th>
<th>Alternative A</th>
<th>Refloat, tow to shore, demolish and dispose onshore.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substructures</td>
<td>Alternative B</td>
<td>Remove external and internal steelwork, refloat and dispose at a deep water location</td>
</tr>
<tr>
<td>TCP2, CDP1, TP1</td>
<td>Alternative C</td>
<td>Remove internal and external steelwork and cut down sub-structure to provide a clear draft of 55m.</td>
</tr>
<tr>
<td></td>
<td>Alternative D</td>
<td>Leave in place, removing as much external steelwork as reasonably practicable.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infield Pipelines and Cables</th>
<th>Alternative A</th>
<th>Remove, transport to shore and onshore disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alternative B</td>
<td>Leave in place but trenched</td>
</tr>
<tr>
<td></td>
<td>Alternative C</td>
<td>Leave in place but bury ends</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drill Cuttings</th>
<th>Alternative A</th>
<th>Remove and onshore disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP2, CDP1</td>
<td>Alternative B</td>
<td>Leave in place</td>
</tr>
</tbody>
</table>

### Figure 3. Evaluations and Comparative Assessments Conducted for Frigg Field Facilities

#### 5.4 Concrete Substructures - Comparative Assessment of Disposal Alternatives

The three concrete substructures, TCP2, CDP1, and TP1, are each different in design. Different procedures would therefore be required for their removal and disposal, each of which present a different set of challenges and uncertainties. All of the substructures had been in-place for more than 25 years and it is likely that some deterioration in their condition may have occurred. At the time these platforms were designed and constructed, consideration of the loading during a future removal operation was not included in the design process. In addition, the mechanical systems used in
controlling and positioning the concrete substructures during installation were only designed for use during that phase, and were thus abandoned when the platforms were in place.

Due to these facts and the complexity and uncertainties associated with full removal and onshore disposal of the concrete substructures, other decommissioning alternatives have also been considered as specifically provided for in Clause 3 and Annex 2 of OSPAR Decision 98/3.

When considering the disposal options for the concrete substructures the technical feasibility of each alternative has been assessed as well as the risk to personnel, impact on the environment and the cost.

Considerable effort has been given to the assessment process. Input has been sought from the engineering companies who were responsible for the original design of the platforms; partner companies; independent consultants; academics from universities in a number of European countries; Det Norske Veritas and TOTAL Group experts.

5.5 Development of Method Statements

The companies involved in the original design and construction of the three platforms in the 1970s were engaged by TOTAL E&P NORGE AS in 1999 to conduct the initial engineering and feasibility studies for the decommissioning of the platforms. The main object of the studies was to assess the feasibility of refloating the substructures. Different methods were considered and a recommended method was proposed by the design companies based upon many engineering evaluations. The recommended method was described in the form of a general procedure or “method statement”, which was then reviewed to identify risks to personnel engaged in the disposal activities. The method statement was then modified as necessary to reduce or eliminate unacceptable risks.

Whilst developing the method statements, new or innovative activities or operations that were beyond current experience were identified. The feasibility of these activities was assessed and the need for programmes to develop the necessary technology was highlighted.

In parallel, the engineering contractors assessed the feasibility of other disposal options (Alternatives B, C and D in Fig. 3 and prepared method statements, which described the proposed method of undertaking the work.

The method statements and engineering studies were reviewed and validated by a group of independent experts including representatives from SINTEF, Norwegian Geotechnical Institute, Noble Denton, Munich University and Det Norske Veritas.
5.6 Evaluation Principles

The following aspects have been considered when evaluating the various disposal alternatives:

- Technical Risk Assessment
- Risk to Personnel
- Environmental Impact
- Cost
- Views from the NGOs

5.7 Technical Risk Assessment

The aim of the technical risk assessment was to estimate, in quantitative terms, the risk of being unable to complete the removal and disposal work as planned. Based upon the risk accepted during the production phase the maximum acceptable probability of a major accident during the decommissioning operations (with the associated large financial loss) has been set as $1 \times 10^{-3}$ (1 in 1000). During marine operations a probability of structural failure ten times less than this (that is 1 in 10,000) should be aimed at.

Offshore inspections and testing were carried out during 1999 and 2000 to determine the condition of certain key mechanical systems and structural elements. The results from this inspection and testing provided additional input and validation to the technical risk assessment.

5.8 Risk to Personnel

In addition to the qualitative safety assessments carried out during the development of the method statements, a numerical assessment of the risk to personnel was conducted. The probability of death or serious injury occurring during the removal and onshore disposal operations was estimated based upon the planned activities and historical accident data for similar offshore and onshore activities. The safety of personnel involved in all the disposal alternatives was assessed.

The TOTAL E&P NORGE AS criteria for acceptability of risk to personnel is that the risk of fatality for an individual shall not be greater than $1 \times 10^{-3}$ per year (1 in 1000) and shall be as low as reasonably practicable. This criterion is in accordance with generally accepted principles applied throughout industry and supported by the UK Health and Safety Executive This is the highest risk that can be tolerated and a risk considerably less than this must be sought.

5.9 Environmental Impact

The impact of the disposal operations on the environment and society has been estimated using generally accepted methods and principles.
The purpose of the Environmental Impact Assessment was to:-

- Clarify the consequences of the relevant disposal alternatives for the Frigg Field facilities that may have a significant impact on the environment, natural resources and society.
- Present information about possible impacts in a manner that can form a basis for a decision on the disposal alternatives.
- Present proposals for mitigating any damage and nuisance caused by the chosen disposal alternatives.

The parameters studied in the environmental impact assessment fall generally into two main categories as listed below.

**Environmental Impacts**

- Energy
- Releases (emissions) to atmosphere
- Releases (discharges) to sea, water, or ground
- Physical impact on the environment
- Aesthetic impact including noise, smell and visual effects
- Waste/resources management
- Littering

**Social / Community Impacts**

- Fisheries
- Free passage at sea
- Costs and national supply
- Employment effects
- Other social impacts

Some of these environmental impacts can be quantified. Where this has not been possible, the assessments of non-quantifiable environmental impacts have been made based upon consideration of the scale of the effect and its value or sensitivity. The assessments are presented using a series of categories ranging from “Very large positive” impact through “Insignificant/No” impact to “Very large negative” impact. The assessment distinguishes the important impacts from those that are less important. This is done by considering the effect of an impact in the area in which it is occurring (“value” or “sensitivity”), combined with the scope of the effect, to arrive at the total impact. By using this method the same magnitude of effect may then give different impacts depending on the value or sensitivity of the impacted environmental component. Additionally, the same type of effect will give a different impact depending on the sensitivity of the recipient/environment.

The overall environmental impact of a particular disposal alternative has been judged based upon the impact on the individual parameters listed above. The significance of both the overall and the
individual impacts has been assessed from both the short term and long term perspective. The Environmental Impact Assessment has been peer reviewed by independent experts in The Netherlands.

5.10 Costs

The costs associated with each disposal alternative were estimated based upon the proposed disposal methods. Possible increases in the cost of the works were also estimated based upon the technical uncertainties associated with the disposal alternatives.

5.11 Views from the NGOs

Input from the stakeholder dialogue process conducted by TOTAL E&P NORGE AS has been particularly useful when assessing the sometimes conflicting requirements of safety, environmental protection, cost and technical risk.

5.12 Comparison of Disposal Alternatives

The predicted consequences, in terms of safety, environmental impact and cost, of adopting the main disposal alternatives considered, are summarised in Figure 4 as an example for the concrete structure TCP2. This table does not include the removal and offshore disposal alternative (Alternative B), as the implications are rather similar to the removal and onshore disposal alternative (Alternative A). In addition society’s general aversion to offshore dumping makes this alternative unattractive.
Based on these assessments it was recommended that the topsides of TCP2 platform should be removed and brought onshore for disposal, and that the concrete substructure should be suitably marked and left in place after removal of the external steelwork. As much as practicable of the equipment and materials brought onshore will be reused or recycled.

5.13 Frigg Field Public Consultation Process

The Frigg Field Public consultation process was a very important element in reaching approval of the recommended disposal arrangements for the Frigg Field facilities. It started in 1999, where the stakeholders were invited to comment on the programme for the Environmental Impact Assessment (EIA). The Norwegian and UK authorities’ consultation with the OSPAR Contracting Parties took 16 weeks. By the end of January 2003, no objections had been raised by any of the Contracting Parties to Norway and the UK Governments’ intention to issue permits to leave the concrete substructures in place. By April 2004, approval of the Frigg Cessation Plan had been obtained from both the Norwegian and UK Authorities.
Because of the difficulties in re-floating the three huge concrete substructures, it was important to allocate sufficient time for the stakeholders to become involved in the process. Their constructive suggestions and recommendations have been very valuable and had an important impact on the content of the Cessation Plan. Figure 5 illustrates the various stages in the consultation process in Norway and the UK in establishing the Frigg Field Cessation Plan.

5.14 The stakeholders

A major key to successful stakeholder consultation is to consult with the right stakeholders at the right time and in the right way. Keeping the Brent Spar affair in 1995 in mind, the TOTAL E&P NORGE team made great efforts to ensure the process was open, honest and transparent involving a large range of stakeholders. The most active stakeholder groups were:

- Governmental agencies
- Fishermen
- Non-governmental organisations
- Environmental organisations
- Academics
the primary group of UK and Norwegian stakeholders involved in the Frigg dialogue process was about twelve individuals and organisations. Regular contact was maintained with this group, which included frequent face-to-face meetings, work-shop, e-mail, telephone and letter contact. The remaining stakeholders have been sent regular updates on the progress of the project, but have not participated actively in the process.

5.15 Some useful lessons learned

- Allow for sufficient time – it takes longer than you think! Involve the stakeholders early before major decisions are taken
- Chose the right team for the consultation process. Involve the senior decision makers (managers) in the face-to-face meetings with the stakeholders.
- Trust is the key word. Show the stakeholders, they can influence the decisions – this cannot be a PR exercise! Deliver on promises of action. Commit to be open and transparent.
- Make sure technical terms and explanations are clearly understood (e.g. risk acceptance criteria)
- Independent studies (e.g. from universities) and peer reviews (verification process) was a key to trust building.
- Communication means:
  - Face-to-face meetings and workshops are the only effective way of forming good relationships and building trust
  - The creation of the Frigg Cessation web site proved to be a flexible and time saving tool to ensure all interested parties could access all key documents
  - Newsletters informing of the different issues arising as the decommissioning process progressed was well received.
  - The use of a animated video illustrating the issues proved to be an excellent way to illustrate the potential technical difficulties associated with floating the substructures. The tool proved very useful in discussions with interested parties and helping them understand highly technical issues.
  - There was no substitute for offshore site visits to help people understand the huge size of the structures.
  - The contact with the interested stakeholders will be maintained until the approved decommissioning programme is completed.

6. REFERENCES

7. LIST OF FIGURES

Fig. 1: Decision logic for production or utility systems
Fig. 2: Decision logic for operational and administrative activities
Fig. 3: Evaluations and comparative assessments conducted for Frigg Field Facilities
Fig. 4: Predicted consequences of different disposal alternatives for the TCP2 concrete substructure
Fig. 5: Decommissioning consultation and approval process in Norway and the UK