Shell Brent Decommissioning Project

Independent Review Group

Final Report

3 February 2017
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Final Report

Summary

The Independent Review Group (IRG) was established in 2007 to review the various studies that Shell would undertake to enable it to prepare for the decommissioning of the Brent Field. The IRG has met 27 times, read and reviewed over 300 reports, and made and considered the responses to over 4600 comments on these reports, reviewing multiple revisions of reports as necessary. Its comments cover the scope, clarity, completeness, methodology, and relevance of the work and the validity of the comparative assessments and the conclusions drawn. The IRG suggested further research or actions needed during the project to address identified information gaps that would otherwise have prevented an informed decision by Shell on the choice of decommissioning options. The IRG has also suggested further research that could be undertaken in the future to tackle problems arising as a result of legacy issues. The IRG is satisfied that relevant comments arising during group stakeholder meetings have also been addressed.

The IRG commends the thorough and extensive efforts made by Shell to acquire, make available and document the information needed in support of the programme, to use the best available methodologies, and the cooperative and constructive response of Shell staff to IRG queries and requests for more information, including in several cases the commissioning of new or expanded studies as a result of suggestions made by the IRG.

The final responsibility for the contents of the reports of studies, however, rests with their authors and Shell, and the IRG does not necessarily support or endorse every statement in the individual reports. In particular the IRG notes that (except in a few instances) neither the Decommissioning Programme (DP) [Ref 1]) nor the supporting documents attempt to quantify the considerable uncertainties in many of the estimates made. This gives the impression of greater confidence in uncertain outcomes than is really warranted. The IRG role has been to address the sufficiency of the evidence base on which the options have been assessed by Shell, and it is not responsible for approving the final options selected by Shell in its proposed DP. As a result of its examination of the evidence assembled by Shell, the IRG has prepared this final report.

Conclusions & Recommendations

1) The IRG has reviewed and commented on reports by Shell and its contractors on all relevant aspects of the DP, and is satisfied that a sufficiently wide range of options have been examined. The IRG has also assessed the rationale leading to the decisions by Shell and confirms that so far as it can judge the scientific, engineering and other evidence used, and the rationale developed, appear to be adequate to enable the decisions to be made. In particular the IRG accepts the evidence that supports the conclusions that
   a) The complete removal of the Brent Alpha jacket is technically feasible, but may well not be the preferred option, because of the trade-off between low technical feasibility and high cost, versus small benefits to fishermen and a limited reduction of the small residual environmental impact expected.
   b) The risks and technical difficulties associated with attempting to remove the Gravity Based Structures (GBS) completely would be much higher than are normally acceptable for major marine operations, and the benefits to fishermen and the environment of doing so in order to leave a small area of clean sea-bed would not be large.
c) Leaving the drill cuttings and cell contents in place means that about 22,000 m$^3$ of hydrocarbons would remain after decommissioning. However, although it is uncertain, the risk of environmental impacts of these should be local and are not likely to extend beyond about 2-3 km from the platforms. There appears to be no reason to expect that the future release of cell content will cause regional or population level effects on pelagic or benthic organisms. For drill cuttings the potential environmental impacts are probably near or below the OSPAR thresholds for further remediation.

d) Attempts to mobilise and remove either the drill cuttings or the cell contents would be likely to create greatly increased volumes of contaminated waste, and the environmental impacts of the recovery, transport, treatment and disposal of these would be likely to be greater than those of leaving the material in place.

e) The evidence supporting the proposals for decommissioning the pipelines, and the related sea bed structures and for debris removal appears to be sound.

f) The disposal of drill cuttings and/or cell contents by re-injection into the formations accessible by wells from the existing platforms was originally considered to be a promising option. However, detailed studies showed that difficulties associated with the technical conditions of the available well stock together with subsurface geological problems made this option impracticable. New wells drilled from a new sub-sea installation located at some distance from the existing platforms would be required for disposal by re-injection. This would entail high costs, in order to reduce the small environmental impacts of leaving them in place. Other options that involve treatment of the cell contents in situ, sediment capping or extraction and platform or onshore treatment, have also been examined but not found to be preferable.

g) While removing the GBS legs is considered to be technically feasible, the risks to operating personnel of cutting the legs to -55 m and removing them would outweigh the risks to users of the sea in the short-term (i.e. for the next few decades), provided the legs are fitted with Navaids (etc.) as proposed. The IRG also recognises that some stakeholders including fishermen’s representatives have expressed a preference for the legs to remain visible.

2) The IRG is, however, concerned that despite strenuous efforts to evaluate it using the best available methods, the evidence available on the risks from leaving the GBS legs standing above sea level in the long term, until they naturally degrade to just below sea level and thereafter until total collapse on to the sea bed, is not reliable. The legs could be cut down to -55 m to comply with the IMO recommendations for a partially removed structure in the long term, and so mitigate the legacy risk to users of the sea, but at present this would be risky and expensive, and may therefore not be the preferred option. The IRG observes that

a) The legacy risk to fishermen and other users of the sea (especially shipping) is extremely uncertain in the longer term (decades to centuries), because it is not possible to reliably predict

i) The mode and rate of degradation of the concrete structures, especially close to the waterline.

ii) The nature and frequency of future marine activities such as ship movements in the area.

iii) The effectiveness of future collision avoidance procedures and practice (which currently prevent the great majority of potential collisions).

b) The proposal that the risks to shipping should be re-evaluated regularly (at roughly decadal intervals) provides a satisfactory means of dealing with the latter uncertainties, by tracking the evolution of such risks and deciding when corrective action may be needed. However, while various options for additional mitigation of the risk may be applicable, such a re-assessment does not guarantee that corrective action, potentially involving structures that may have become seriously unstable, will be feasible when it is needed. Moreover, it is possible that the policy and regulatory requirements (either UK, IMO or OSPAR) may change in the future (e.g. concerning toppling) and require or enable further action.

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1 The Environmental Statement [ref 12] refers to 16,000 tonnes of total hydrocarbons in the GBSs that may become exposed to the marine environment at some time (Table 0-5), in addition to about 5,600 tonnes of hydrocarbons estimated to be contained in the sea bed and cell top drill cuttings that are currently exposed.
c) These concerns are likely to apply to all similar GBS, and the IRG considers that it is likely to become necessary to cut, remove and dispose of all GBS legs eventually, and therefore suggests that Shell and other GBS operators should plan for the execution of this work in the foreseeable future, before the legs become significantly structurally degraded, and collaborate to develop the technology for doing so, including carrying out underwater cutting trials when appropriate, possibly by means of a suitable Joint Industry Programme.

3) Assembling the necessary evidence on some aspects of the programme has proven to be difficult, despite the very extensive efforts made by and on behalf of Shell.
   a) In particular, the evidence supporting leaving the cell contents in place may be considered adequate to support the EIA, but is still uncertain because,
      i) The information available to verify the nature, quantity and composition of the cell contents is limited to that obtained from the Brent Delta cell sampling (3 cells), Brent Delta attic oil recovery (water samples from 3 additional cells), and an additional sonar sounding on Brent Bravo.
      ii) There is great uncertainty about the timing, mode and rate of eventual release of the cell contents to the environment.
      iii) So far as the IRG is aware the modelling tools available at present were not designed to evaluate the fate and environmental consequences of cell contents release.
   b) While the IRG does not consider that further observations, modelling or analysis would have been likely to affect the main conclusions reached in this case, the situation remains unsatisfactory. In order to reduce the uncertainties and also facilitate similar work in the future, the IRG suggests that Shell and other GBS operators should support continuing sampling and observations of GBS contents, and the development of better models to improve the reliability of the evaluation of the fate of cell contents and other potentially polluting materials present within such structures.

4) If the legs have been cut, it may or may not be possible to re-use or recycle them economically. The costs and risks of bringing them to shore and disposing of them there are expected to be significant, and the environmental impact of placing them on the sea bed adjacent to the platforms is likely to be small. If the legs are left to degrade they will either decay progressively or eventually topple to the sea bed by default (i.e. in the absence of action to prevent it). The IRG therefore suggests that Shell and other GBS operators should request BEIS to consider whether the current UK policy preventing deliberate “toppling” might usefully be updated to permit controlled emplacement of inert major components of decommissioned GBS platforms adjacent to them.

5) Shell has proposed a well-considered survey programme to assess any environmental changes to the sea bed adjacent to and remote from the platforms, once decommissioning of the Field is complete. However, a programme for longer-term monitoring of the structures remaining in place has not yet been proposed, but is to be agreed between Shell and BEIS once the Decommissioning Programme is accepted. The IRG considers that some stakeholders would welcome initial proposals being included in the DP.

6) The IRG notes that the research being undertaken by the collaborative industry-funded INSITE\textsuperscript{2} programme should in future also enable better assessments of the balance of benefits and adverse ecological impacts of leaving GBSs in place. The IRG commends Shell’s support for this programme, and suggests that it should be continued.

\textit{Note: This Final Report is based on the DP and supporting documentation submitted for Consultation by Shell in February 2017. It therefore does not take into account any changes that may be made to these documents after submission, as a result of consultation or otherwise.}

\textsuperscript{2} Declaration of Interest: Two IRG members are also members of the INSITE Scientific Advisory Board.
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1. Introduction

The Brent Field facilities, installed in the early 1970s and operated by Shell on behalf of Shell and Esso Exploration and Production UK (“Esso”), lies off the north-east coast of Scotland, mid-way between the Shetland Islands and Norway. It was one of the largest fields in the North Sea and was served by four large platforms – Alpha, Bravo, Charlie and Delta. Each platform has a “topside” which is visible above the waterline and houses the accommodation block, helipad, as well as drilling and other operational areas. The topsides sit on much taller supporting structures, or “legs”, which stand in 140 m of water and serve to anchor the topsides to the sea bed. For Brent Alpha, the “legs” are a steel structure or “jacket” while for the other platforms the “legs” are concrete structures with a complex of storage cells at the base. A description of the Brent Alpha jacket is given in Section 4.1.1 and the GBS for Brent Bravo, Charlie and Delta are described in Sections 4.1.2.1 and 4.1.2.2. [Refer to the Shell Decommissioning Programmes (DP) [ref 1] and the relevant Technical Documents (TDs) for more details] Brent South was a sub-sea installation, where drilling was performed using a semi-submersible rig. The sub-sea wells at Brent South were taken out of service in 1996 and the wellheads removed and taken to shore in 2004/5, so that all that remains is the drill cuttings pile. The DP takes account of these structures, and also the pipelines and the drill cuttings produced during drilling of the wells at each location.

In 2006, as the platforms in the Brent Field approached Cessation of Production, Shell invited Professor John Shepherd to establish a group of specialists to review the various studies that Shell would undertake to enable it to prepare for decommissioning the Brent Field. Professor Shepherd invited a number of experts to become members of an Independent Review Group (IRG), which started its work on 30th January 2007. Professor Shepherd was empowered to invite others to contribute expertise to the work of the IRG as the need arose. During 2012, the need for additional expertise on the subject of sub-sea re-injection of cell sediments became apparent, and other specialists were invited to contribute to the IRG on this subject. The Terms of Reference and membership of the IRG are summarised in Section 2 and presented in detail in Annexes 1 & 2.

The general procedure used by the IRG in assessing the Shell proposals for decommissioning of the Brent field has been described in a paper [ref 2], which summarises the contributions that an IRG has made to the Brent Field decommissioning project and a range of other projects over a 15-year time span.

The decommissioning of offshore oil and gas installations and pipelines on the United Kingdom Continental Shelf (UKCS) is controlled through the Petroleum Act 1998, as amended by the Energy Act 2008 [ref 3]. The UK's international obligations on decommissioning are governed principally by the 1992 Convention for the Protection of the Marine Environment of the North East Atlantic (the OSPAR Convention [ref 4]). Agreement on the regime to be applied to the decommissioning of offshore installations in the Convention area was reached at a meeting of the OSPAR Commission in July 1998 (OSPAR Decision 98/3 [ref 8]). The OSPAR Commission is made up of representatives of the Governments of 15 Contracting Parties and the European Commission, representing the European Union. The OSPAR regulations generally require complete removal of offshore installations when they are decommissioned, but OSPAR Decision 98/3 allows for a derogation to be sought to allow GBS and the footings of large steel platforms to be left in place.

In the UK the responsibility for ensuring that the requirements of the Petroleum Act 1998 are complied with rests with the Department for Business, Energy & Industrial Strategy (BEIS; formerly the Department of Energy and Climate Change, DECC). BEIS is the competent authority on decommissioning in the UK for OSPAR purposes and provides Guidance Notes, previously issued by DECC, for the Decommissioning of Offshore Oil and Gas Installations and Pipelines [ref 5]. These set out the measures to be taken to decommission disused installations and/or pipelines but are not intended to be prescriptive. The decommissioning process can cover a wide range of activities in addition to removal of the installations, such as handling of drill cuttings and radioactive scale (NORM), removal of
debris from the sea bed and environmental monitoring of the area before and after the decommissioning activity.

The department aims to be transparent in its consideration of decommissioning programmes. As a result, other government departments/agencies, non-governmental organisations, members of the public and other bodies are given the opportunity to comment on the proposals set out in a programme. The engagement of interested stakeholders is recognised as important in order to assess and take account of the views of different interest groups. In addition to stakeholder engagement the DECC/BEIS Guidance Notes suggest that it is important that the studies and the assessment process that supports the chosen decommissioning option are subject to independent expert verification. The purpose of this verification is to confirm that the assessments are reliable, but not to support or oppose the final weighting and balancing of the options, which remains the responsibility of the operator. The guidelines suggest that this may involve the establishment of an independent review process to evaluate the scope, quality and application of the work undertaken and that experts in particular fields may be engaged to evaluate and confirm specific aspects of the project. Shell followed these recommendations in establishing the IRG for the Brent Field decommissioning.

In accordance with the DECC/BEIS Guidance Notes, Shell has used a Comparative Assessment Process to guide the selection of preferred options; this is discussed in Section 4.6.

In addition to the OSPAR requirements, the International Maritime Organisation (IMO) has issued and maintains Guidance concerning provisions to promote the safe passage of ships. [ref 6] This is not legally binding, but specifies that sub-sea installations should allow for 55 m of clear water below the surface. This is relevant to decommissioned GBS and the issue of whether or not their legs may be left standing, especially since they will eventually suffer partial degradation down to or below the water-line (see section 4.1.3).

2. Terms of Reference & Membership

The overall remit for the IRG was to consider and evaluate the adequacy of the evidence produced by Shell to support its plan for the decommissioning of the four Brent platforms and associated pipelines once the topsides have been removed; consideration of the topsides was not included. However, the IRG did give some consideration to restrictions that may arise with decommissioning activity if topsides were removed prematurely. The full Terms of Reference for the IRG for the Brent Field decommissioning are given in Annex 1. In essence, these are as follows:

- To provide peer review of the quality of studies carried out. The final responsibility for the contents of reports of studies, however, rests with their authors and Shell, and the IRG does not necessarily support or endorse every statement in the individual reports.
- To evaluate the scope of the work for the various studies. The specification of these lies with Shell but the IRG may suggest additional topics or other options for investigation.
- The IRG will not comment on the final options which emerge from the Comparative Assessments and are selected by Shell. Its role is to ensure that an appropriate range of options has been examined in sufficient depth so that the information available is adequate for a rational decision to be reached by Shell.
- The IRG or any member will have the right to publish the findings arising from the group’s reviews/activities.

The IRG is paid for by Shell through a contract with DNV-GL and operates independently. Its members all have an academic background but also a wide range of industrial and environmental experience, and work as part-time paid consultants for Solutions to Environmental Problems (Pridetime Services Ltd.) under contract to DNV, but none is professionally or financially dependent on this work. The final
bullet above is a further crucial guarantee of the independence of the IRG, as the IRG may publish its findings as it wishes, without approval by Shell (or anyone else).

The IRG started its work on 30th January 2007, and the core membership has remained unchanged throughout as follows:

- Professor John Shepherd, Chairman
- Professor Torgeir Bakke
- Professor Günther Clauss
- Professor William Dover
- Professor Jürgen Rullkötter
- Professor W. Brian Wilkinson
- Mr. Richard Clements, Secretary

The specialists invited to contribute to the IRG on the subject of sub-sea bed reinjection of cell sediments were:

- Professor David Davies
- Professor Quentin Fisher
- Professor Ian Main

Information about all the members of the IRG is given in Annex 2.

3. Activities

3.1 Review Process

A first step for the IRG in considering the large number and wide range of studies, which were to lead through to the final Shell decommissioning proposals, was to agree a procedure with Shell for the Review Process. This Process involved:

- Receiving selected study reports from Shell and the preparation of IRG reviews (involving several IRG members) in a standardised format.
- Meetings between Shell and the IRG at which Shell described the progress to date with its decommissioning programme (studies, field work, surveys etc.), and the IRG offered its review findings on the study reports that had been received and suggested options on which further analyses or additional work were needed (for example extended laboratory testing) to improve the level of reliability of a study. These meetings provided an essential and valuable interaction between the IRG and Shell. In most cases there were several iterations between the IRG and Shell, possibly extending over several months, before the IRG was able to offer its close-out comments on a study report.
- Private IRG meetings usually both preceded and followed the IRG/Shell joint meetings.
- In one case, a meeting was held with a Shell contractor, at which the IRG discussed study findings and commented on specifications for future work.
- All documentation, emails and other correspondence was circulated to all core IRG members although those with appropriate specialist knowledge took the lead with reviews of the relevant supporting studies. Every core IRG Member contributed to the reviews of the higher level Technical Documents and the draft Decommissioning Programme. Figure 1 shows in a general way the interactions and links between a Commissioning Organisation (CO), Shell in this case, and the IRG.
• The IRG had to examine about 300 documents relating to Brent Decommissioning. It found that the most effective way of proceeding was to work from the “bottom up”, i.e. firstly to consider the supporting studies that were to be used by Shell in the development of higher level policy documents leading through to the Brent Field Decommissioning Programmes document for submission to BEIS. This “bottom up” approach enabled the IRG to assess whether:
  • The basic evidence was sound, i.e. is the quality of the science, technology etc. satisfactory?
  • The synthesis and utilisation of the evidence was sound, i.e. has the detailed evidence been properly carried forward into the Technical Documents, Environmental Statement etc. and then to the Brent Field Decommissioning Programmes?

3.2 Meetings

The IRG met on 27 occasions. The meetings were chaired by Professor Shepherd who also set the meeting agenda in consultation with Group members and Shell. The general format was for the IRG to meet privately for the first part of the meeting to consider what work was outstanding and to identify the major issues that it wished to raise with Shell. This was usually followed by a session with Shell personnel present. The Chairman introduced any major points that the IRG wished to discuss and gave an update on IRG activities. Shell described the current state of the Brent Decommissioning project. The reports being reviewed by the IRG were discussed and any potentially contentious points were brought to the attention of Shell. Shell reported on any Stakeholder interaction. Formal notes of the meetings were produced and agreed between the IRG and Shell before being used as the basis of the text for the IRG web site (see 3.5 below).

Since the time between some meetings extended to several months, a number of teleconferences between the IRG and Shell were held in the intervening periods. IRG members also participated as observers in Stakeholder Meetings and other specialist meetings arranged by Shell to contribute to the project (e.g. the CMSTG) and these are described in Sections 3.3 and 3.4 below.

The membership of the IRG remained the same throughout the Brent Decommissioning programme with a chairman, five technical experts and a secretary. Three additional members were co-opted for a short period when reinjection of the cell contents was being considered. Shell personnel changed significantly during the project, with a new Project Director, Decommissioning Programme Manager
and Engineering Manager, reflecting the recognition that the programme was broad, expensive and expanding. In addition, the engineering team had been expanded. The Engineering Manager changed again after another four years, when the emphasis also changed from an exploratory and justification phase to programme definition.

In the early stages of the project the interactions between the IRG and Shell were sometimes unproductive, but once clear working procedures had been agreed the arrangements worked well. At first the reports presented to the IRG tended to be the Shell syntheses of the contractors’ reports, and the IRG needed to request the source reports to ensure that the evidence base supported the conclusions drawn. With one exception, the IRG did not meet any of the contractors to discuss review comments although it did suggest that this could have improved the process.

3.3 Stakeholder Interaction

One or two IRG members have attended all Stakeholder Events as observers, in order to respond to questions about the work of the IRG, and to maintain its awareness of stakeholder concerns and interests so far as possible [see ref 19]. Shell has also conducted numerous face-to-face meetings with stakeholders, and the IRG may therefore not be aware of concerns expressed in these private meetings. However, the IRG worked independently and not as the agent of any stakeholder, although it has taken their views into account as appropriate.

3.4 Working Groups & Other Meetings

3.4.1 Cell Contents Management Stakeholder Task Group (CMSTG)

The CMSTG was established to enable Shell to explore the views of selected stakeholders on the options for dealing with the GBS cell contents. One or two IRG members attended all meetings of the CMSTG as observers and participated in the discussions but not in the solicitation or expression of stakeholder opinions. The CMSTG participated in a detailed Multi-Criterion Decision Analysis (MCDA) of the options, facilitated by expert consultants. The results of this are reported briefly in the GBS Cell Contents Decommissioning Technical Document [ref 7], but were not used in the final option selection, for which an alternative MCDA prepared internally by Shell was used as the analytical basis. The IRG does not know to what extent the scoring and weighting of the options by Shell was influenced by the CMSTG work. The results of the two analyses are significantly different. It is difficult for non-experts who are not fully aware of the importance and role of normalisation and swing weighting in MCDA to participate effectively in choosing weightings, which can be extremely influential (see Section 4.6 on the Comparative Assessment process). The opinions of stakeholders can and do moreover vary considerably, and it is difficult to accommodate this within the analytical process except by means of sensitivity analysis. The IRG evaluation of the selection of the preferred option for the cell contents is dealt with in Section 4.2.4.

3.4.2 GBS Peer Review Workshop

The workshop organised by Shell was an overview of the work done to achieve the overall findings of the technical risk assessments associated with Brent Bravo and Brent Charlie refloat, tow and inshore dismantling as well as studies concerning leg removal. Three IRG members attended the meeting as observers. The workshop lasted two days and concentrated on Refloat (Day 1) and Leg Removal (Day 2).

For Refloat it was decided that only a qualitative assessment was possible and that this should attempt to find clear “show stoppers”. For example, given its criticality, it was suggested that the pull-out resistance of the skirts for Brent Charlie be subject of further geotechnical analysis.
For Leg Removal consideration was given to weather constraints including further analysis of proximity effects (legs close together causing more extreme variations in sea states, particularly for storm conditions). However, the general view was that it would be difficult to argue that weather conditions would be the constraint.

The general view at this workshop meeting was that, even though not proven, leg removal appears likely to be feasible. The efficacy of the cutting methodology for highly stressed, thick, heavily reinforced concrete sections, which simulate the leg structure, has been demonstrated with land-based trials but is unproven for underwater marine conditions. It was recognised that internal steelwork may present a particular problem. The only way of reducing the uncertainties would be to conduct field trials. Although both contractors’ studies suggest that leg removal would be technically feasible, the cutting methodology in particular would need to be proven by representative and realistic trials before the efficacy of the technique would be assured with reasonable confidence. Until such trials had been conducted, the technical feasibility of removing the legs could not be assured but could not be discounted either. A more detailed examination of lifting requirements would also be required.

3.4.3 Environmental Scoring Plenary Workshop

This workshop brought together relevant experts from DNV-GL and members of the Shell team to establish appropriate scores for the environmental impacts of options being considered in the Comparative Assessments. Two members of the IRG were present as observers at the Plenary Workshop. DNV-GL staff, after assessing the potential environmental impact for each of the decommissioning options for the facilities (platforms, pipelines etc.), which Shell was to subject to a Comparative Assessment, had assigned a reasoned scoring for the two environmental impact CA sub-criteria (operational environmental impacts and legacy environmental impacts) and impacts on the communities sub-criterion. These scores were then carried forward to a plenary workshop, facilitated by Catalyze, at which DNV-GL adjusted the scores to fit to a global scale for each of the sub-criteria, a process similar to that adopted for the Technical Feasibility Workshop as described below. These modified scores were then used in the CA process. The meeting was characterized by lively, constructive and well-informed discussions, and substantive responses by the relevant experts. The IRG members and Shell staff were able to ask questions and contributed to the discussions, but did not participate in the scoring process.

3.4.4 Technical Feasibility Scoring Plenary Workshop

This was attended by Esso and Shell personnel, together with two facilitators from Catalyze and two members of the IRG. The IRG members were there to observe and did not assist in the scoring but were able to ask questions.

Lively, constructive and well-informed discussions took place. The object of the exercise was to score the Technical Feasibility of all the activities in the range of 0-100%. In essence the scores were in increments of 10%, occasionally 5%.

The meeting lasted 2 days, giving scores for all activities by the end of day one and then a review of these scores during day two. An attempt was made to compare between some very different activities so that the final values could be used in the Comparative Assessments. The drill cuttings within the Brent Delta and Bravo tri-cells were not considered at the workshop. However as Shell considers that they are similar to the cuttings on the seabed and may therefore be treated like undisturbed drill cuttings piles under OSPAR Recommendation 2006/5, they were not subject to a CA. Subsequent efforts have been made to sample the Brent Delta tri-cell drill cuttings to confirm their characteristics as per the OSPAR Recommendation (see Section 4.2) although this does not strictly apply.
3.5 Web Site

Throughout the period of the Brent Decommissioning project, the IRG maintained an account of its activities as a separate section of the Shell Brent Decommissioning web site information on stakeholder engagement. [see http://www.shell.co.uk/sustainability/decommissioning/brent-field-decommissioning/brent-field-stakeholder-engagement.html]

The establishment of the IRG in January 2007 was reported together with the Terms of Reference for the IRG (see also Annex 1) and a summary of its role. Details of its members are posted at http://www.shell.co.uk/sustainability/decommissioning/brent-field-decommissioning/brent-field-stakeholder-engagement/irg-members-details.html (see also Annex 2).

A brief outline of the main topics discussed during each meeting was recorded by the IRG and submitted to Shell to be posted on the web site [see http://www.shell.co.uk/sustainability/decommissioning/brent-field-decommissioning/brent-field-stakeholder-engagement/irg-activities-to-date.html and also Annex 3]. Whilst Shell had an opportunity to comment on the technical accuracy of the information posted, the IRG is responsible for the views expressed.

4. Evaluations

4.1 Platforms

4.1.1 Introduction

As described in the Decommissioning Programmes and elsewhere, the Brent Field installations involve four platforms, one steel jacketed and three concrete gravity based structures, none of which were designed for eventual removal, and the wells at the Brent South sub-sea installation. Before planning to dispose of these, Shell examined possible re-use options. Of these one of the most promising initially appeared to be for CO₂ disposal as part of a Carbon Capture & Storage (CCS) programme. The IRG is, however, satisfied that the detailed examination of this option [ref 1] indicated that it would not be viable in the foreseeable future because of the location of the field, far from land, and metallurgical unsuitability of much of the infrastructure. Other possible re-use options were rendered unattractive by the high cost of maintaining the platforms in a state suitable for habitation.

The provisions of OSPAR Decision 98/3 and the DECC/BEIS Guidance would ideally require all of the platforms to be removed, but allow for a derogation to leave the footings of large steel platforms and the major part of GBS platforms (excluding topsides) to be left in place if this can be demonstrated to be a preferable option. The IRG has critically reviewed the technical studies undertaken to investigate the practicability of removal of the GBS and the footings of Brent Alpha; these are described below. In summary, even if it was possible to refloat the GBS platforms, the options for their re-use would be very limited, and the comminution and recycling or disposal of such large quantities of concrete on land would be problematic. However, the over-riding factors in relation to GBS refloat are found to be the technical difficulty and associated high risk of project failure and thus also risk to project personnel that are not adequately offset by the small reduction of legacy environmental impacts, or the value of materials recovered.

4.1.2 Brent Alpha Jacket

The Brent Alpha platform was installed in the field in 1976. The platform comprises a lower steel jacket and topsides. The topsides will be lifted off and taken to shore before the jacket is decommissioned. The following section refers only to the proposals for decommissioning the steel jacket [see ref 16]. The jacket is secured to the sea bed by long steel piles. They are bonded to sleeves
on the jacket by cement grout. That part of the jacket lying between the top of the piles, extending above the pile sleeves and the sea bed is called the footings; these extend about 56 m above sea bed.

Drill cuttings that contain high concentrations of hydrocarbons lie between the legs up to a maximum height of 4 m and surround the platform and extend outwards as a shallow cone. No part of the jacket structure has been used for the storage of hydrocarbons or other chemicals. Consequently, there should be no cause for concern with respect to the release of potentially polluting substances from the jacket itself once the leg sections are cut.

An OSPAR 98/3 requirement [ref 8] is that all steel jackets in the North Sea shall be totally removed to leave a clear sea bed if the jacket weight is less than 10,000 tonnes. If the jacket weight is greater than this, a derogation application may be made for partial removal. The estimated total weight of the Brent Alpha jacket if cut at 3 m below sea bed is 25,834 tonnes [dry wt]. Thus, Brent Alpha may be partially removed but Shell must apply for derogation. To satisfy this requirement a Comparative Assessment between the derogation options must be examined.

A range of decommissioning possibilities was examined, analysed and reported by contractors and consultants. [ref 16] All of the principal reports were reviewed by the IRG.

During the decommissioning studies three possibilities were considered:

a) Re-use  
b) Total removal to land  
c) Partial removal to land.

Re-use: A number of studies showed that there were no promising opportunities for continued use of the Brent Alpha platform either for future hydrocarbon production or for carbon capture and storage. All other non-oil/gas activities examined were technically infeasible or economically non-viable.

Total removal: Studies were made of the way one could remove the total jacket, including the footings. A first step required the steel piles to be severed from the footings at 3 m below the sea bed. Reverse installation would then require the buoyancy legs to be watertight but these had been subject to many penetrations since installation and this could not be assured. The provision of secondary buoyancy units was examined as was the removal of the footings and upper jacket using a single lift vessel but principally on the grounds of structural problems both these approaches were shown to be infeasible. It was considered that the upper jacket could be cut at -84.5 m LAT and removed in a single lift.

To remove the footings two approaches for severing the steel piles so as to free the structure from the sea bed were considered and shown to be technically feasible. The steel piles may be cut either externally or internally. To cut them externally would involve accessing the steel piles by excavating trenches in the drill cuttings to a depth of 4 m into the sea bed. This would inevitably lead to some spread of pollution in the marine environment. In response to a suggestion by the IRG, Shell also examined the option of cutting the steel piles internally. This would involve reaming out some of the cement grout in the piles prior to cutting at 3 m below sea bed. The technology to achieve this is available but because of the large diameter (1.83 m) some additional developments may be needed. This approach would lead to some disturbance of the drill cuttings when the steel piles were withdrawn but it would be small compared with that resulting from excavations needed for external cutting. A cut at the -84.5 m level would give reader access to the top of the steel piles for internal cutting should this be selected.

Partial Removal: The third option would be to cut the legs at -84.5 m LAT. This level of cut would meet the requirement of the International Maritime Organisation (IMO) for a clearance of at least 55 m below sea level. The upper jacket could be lifted using the SLV for transport to shore. The footings remaining on the sea bed are likely to be protected by the anodes only for about twenty years.
Thereafter, the legs and steel piles would progressively corrode and collapse. These degradation processes would take some considerable time, and there may still be the residue of the steel piles sticking out of the sea bed in 500 years’ time.

Since derogation for partial removal of the Brent Alpha jacket (leaving the footings in place) may be sought, a Comparative Assessment of the various removal options was made. It emerged that on the basis of the weightings of the criteria used within the CA (see Section 4.6) partial removal with footings left in place was preferred to either total removal option.

The recommendation from Shell is that partial removal is the preferred option and derogation should be sought. The IRG considers that both partial and full removal are feasible but it is outside its brief to comment on the final selection. The IRG confirms that so far as it can judge the scientific, engineering and other evidence used to identify and assess the options considered is soundly based.

4.1.3 Gravity Based Structures: Prospects for Refloat & Removal

Gravity Based Structures (GBS) are large, heavy structures made of concrete with reinforced steel bars and pre-stressed with high-tensile steel tendons. They rest on the sea floor under their own weight. There are three such structures in the Brent Field: Brent Bravo, Delta and Charlie. Brent Bravo weighs 341,000 tonnes, Delta 325,000 tonnes and Brent Charlie 296,900 tonnes (Note: these are weights without topsides or water ballast and without any of the solid waste residues in cells or legs). The platforms were constructed in the early 1970s and were installed in about 142 m of water [see ref 17].

4.1.3.1 Brent Bravo and Brent Delta

Brent Bravo and Brent Delta are both Condeep designs manufactured in Norway in the early 1970s. They comprise 19 circular cells on the sea bed each with an internal diameter of 18.54 m arranged in a hexagonal grouping with the total caisson covering an area of 90 x 100 m and a height of 60 m above sea bed. The top of the cells are domed. The areas, where the circular cells intersect the spaces between them, are called tri-cells. These tri-cells are filled with some ballast at the bottom, contain drill cuttings and are open to the sea at the top. The cells are fabricated from reinforced concrete and have a wall thickness of 0.73 m. The caissons are secured to the sea bed by steel and concrete skirts that penetrate about 4 m into the sea bed. Both Bravo and Delta are three-legged platforms. The legs extend upwards from three of the cells to support the topside. The legs vary from about 20 m diameter at the base to 12 m at the top. The concrete walls vary from 1.55 to 0.55 m in thickness and carry pre-stressed high-tensile steel tendons. The other 16 cells were used to separate oil from produced water and sand and for oil storage. One of the legs in each of the Bravo and Delta platforms is a “Utility Leg” and contains pumping equipment, pipes etc. to control flows of oil and water through the 16 cells. It also has a header tank to maintain the hydrostatic pressure in the 16 cells at some 4 atm below sea level. This so-called “drawdown” condition ensures that the cell structures are under compression. Concrete is very weak in tension, and hence the use of drawdown is essential for the structure as it provides compressive loading. However, it makes it difficult to access the cells for sampling or other purposes as the drawdown must be maintained during the process of accessing a cell. The method to overcome this is known as hot tapping. The water level in the other two legs, i.e. the “Drilling Legs” is held at 5 m below sea level in Bravo, and in Delta the “Drilling Legs” are open to the sea.

As with Brent Alpha no provision appears to have been made at the design stage for removal, in this case by refloat. The platforms are now heavier than when installed, due to cell sediments, marine growth, grouting under the base and the likelihood that sea bed material would adhere to the base if lifting was attempted. Many reports from contractors and consultants assessed the necessary work before floating, tow to shore and onshore/near shore deconstruction. The issues raised concerned the many penetrations to sea (and whether these could be sealed effectively), the installation of a system to
provide hydraulic pressure under the base to free the structure, a buoyancy arrangement to allow refloat but prevent uncontrolled ascent, and provision of onshore/near shore docking arrangements and others.

Based on all these studies Shell concluded that considerable technical development would be needed to provide refloat solutions. These were conceivable in principle, at the desk study level. However, in practice implementing this work would involve a Health and Safety risk and project failure risk on floating, towing and onshore disposal that would be much higher than is regarded tolerable to the offshore industry. Shell has concluded that leave in place is the best option and intends to apply for derogation. The IRG reviewed all the relevant reports, offered detailed critiques where appropriate and examined the rationale leading to Shell’s decision. The IRG confirms that so far as it can judge the scientific, engineering and other evidence used to reach the decision was soundly based.

4.1.3.2 Brent Charlie

Brent Charlie is a four-legged Seatank concrete gravity based structure with a 90.5 x 90.5 m square caisson comprised of 36 rectangular reinforced concrete cells. Cell walls are 0.7 to 1.0 m thick. The cells are attached to a base slab and closed by trapezoidal roofs.

The caisson has 4 m deep skirts which penetrate the sea bed. It rises 57.34 m above sea bed level. Four of the cells are extended upwards as legs which support the topsides. The legs vary in diameter from 14.9 m at their base to 8.8 m at sea level. The leg concrete walls vary from 0.9 to 0.4 m in thickness and carry pre-stressed high-tensile steel tendons. As with the Condeep platforms, the water level is controlled to give a drawdown of 36 m so as to provide additional compression on the caisson cells to enhance structural integrity. This lowered water level is maintained in the cells and in three of the legs which are interconnected. The fourth leg contains pumps and other operational equipment, and the water level is about 75 m below sea level. It is not connected to the other three legs. The cells are used for the separation of oil and produced water and sand and for oil storage. There are openings between some of the cells, and there is a tortuous flow path for the oil and water. Only the 10 most central cells have been used to store oil but there may have been accidental overflow of small quantities of oil into adjacent ballast cells. Other than in the Condeep platforms, the 40 conductor tubes for the wells run directly from the topsides through guide frames located between two of the legs, through two of the cells and into the sea bed.

Brent Charlie is quite different from the other two GBS platforms as it does theoretically have sufficient buoyancy to overcome the estimated skirt retraction force and could be floated. However, using buoyancy alone would potentially introduce dynamic and structural instabilities that would be difficult to predict with sufficient confidence. Another primary area of uncertainty for Brent Charlie concerns the guide tubes and the forty conductors, which penetrate the base of the structure. Plugging these openings and verifying that they will remain watertight during refloat would be a major problem. It is considered unlikely that these openings can all be sealed sufficiently and the seals verified for refloat. There is also internal steel pipework which was used during installation but not for operational purposes. This is likely to have degraded leading to connections between inner and outer cells. Sealing such inaccessible openings would be very difficult. These cross-connection openings could result in a free water surface condition across the cells. If the break-loose force or skin friction is not evenly distributed and one side of the structure breaks free more readily than another, the structure would tilt as it departs the sea bed, potentially leading to unwanted heave, pitch and roll motions during ascent. As a consequence, the connection between the caisson roof and the outer wall could fail.

Given the difficulties with plugging, the geotechnical considerations (skirt retraction forces, predicted and actual), the hydraulic capacity of the soil and estimates of GBS weight and eccentricity, it would be extremely difficult to determine the dynamic behaviour of the platform during refloat. As with Brent Bravo and Delta, Shell has decided that the health and safety prospect and total project failure risks are too high to recommend attempting refloat.
The IRG has read and assessed all the reports produced by the contractors and consultants for Shell and provided detailed criticisms where necessary. It has also assessed the rationale leading to the decision by Shell and confirms that so far as it can judge the scientific, engineering and other evidence used to reach the decision was soundly based.

4.1.4 GBS Left in Place: Legs Up/Down

Given the possibility that the GBS platforms may be left in situ, there remains a question as to how much of the platform should be left. The key decision here is whether the legs should be cut down to leave at least 55 m clearance or left protruding above the surface of the water (with appropriate navigational markers) in accordance with the IMO Guidance. Shell has studied these two possibilities in some detail.

Leaving the Legs Up creates an obstruction that would constitute a danger for users of the sea that is at variance with the intention of the IMO Guidance, and this situation could last for hundreds or even a thousand years or more. The IRG notes that this option is, however, favoured by some stakeholders (notably fishermen) who would prefer any residual structures to remain visible.

There is no information on the long-term decay of reinforced concrete over periods of several (perhaps many) hundreds of years as reinforced concrete has only been in use for less than 160 years. Thus, prediction of what will happen to the Brent structures is very uncertain. However, it is possible to assess the likely stages of leg deterioration, and Shell commissioned expert studies to explore the issue.

The collapse of the upper part of the legs would be expected to occur initially in and around the splash zone due to the action of waves and current. The mechanism would be concrete and steel degradation. Shell’s consultants suggest a timescale of 150 to 250 years for this degradation. During this period debris including sections of partially collapsed legs would fall on the cells. It cannot be assumed that the cells would survive these impacts. Recent analysis of concrete core samples has shown that the concrete used for the Brent platforms displayed evidence of alkali silicate reaction (ASR) which reduces the strength of the concrete. Chloride had also penetrated the concrete as evident from the cores. This will in time cause deterioration of the steel reinforcement. The timescale for the suggested degradation of the upper legs and the whole structure may therefore be reduced, possibly by 50 years.

It is possible that the remaining part of the leg just below the sea level could last intact for 500 or even 1000 years as the wave effect decreases and the overturning moment on the leg also decreases. Fatigue is considered to be unlikely as in concrete it is the high end of the load spectrum that causes fatigue damage, and this will decrease as the leg gets shorter.

The IRG considers that during this period, when the legs have collapsed to below sea level, the structure would not comply with IMO guidance for partially removed structures, with no part of the structure remaining above sea level. If it became necessary to establish 55 m of clearance for partially collapsed legs this could give rise to difficult dismantling work. Shell engaged consultants to assess the failure of the Brent concrete structures. The consultants in particular studied the uncontrolled collapse of the structure and also the ways in which controlled toppling could be used to place the legs on the sea bed. If the legs are left standing they will eventually topple in an uncontrolled manner causing considerable damage to the cells and release of oily sediments and disturbance of the drill cuttings. Controlled toppling may be a preferable alternative to the eventual uncontrolled toppling, but it is currently against the government policy. In this circumstance, given the risks associated with dismantling (cutting and bringing the legs onshore for disposal), it may be worth examining controlled disposal offshore. It would also be much less costly. However, in view of the present government policy Shell did not consider it appropriate to include this as one of its decommissioning options.
It is therefore possible that due to wave action the top of the legs could decay within one or two hundred years and then remain just at or below the water surface for a very long period of time, perhaps the most dangerous configuration for users of the sea. Shell examined this possibility as a worst case and engaged specialist consultants to estimate the risks to other users of the sea (as discussed below).

A "near miss", in which a major incident is just avoided, is also of concern. There are only limited data available, and so it is difficult to predict the occurrence of a "near miss". However, an accident that is narrowly avoided could also lead to the regulating agency requiring additional measures to mitigate the risks, and possibly requiring the legs to be cut. If degradation of the upper section of the leg has occurred removal of the leg in such a condition could be a very difficult and dangerous procedure.

The Legs Down option would require more complicated engineering studies of the feasibility of cutting and lifting the legs, transporting them to shore, and demolition on shore. If the legs are to be cut, the cut level will have to be at least 55 m below sea level to meet IMO requirements. All of these aspects have been considered in detail and even included successful onshore experimental cutting of large steel reinforced concrete blocks subjected to compression to simulate the stress in the legs. It was found that cutting was possible using diamond wire. Clearly, offshore cutting would be more difficult, so several feasibility studies have been carried out by contractors. These found that the legs may need support during cutting and one contractor’s study estimated that about 35 flat jacks to act as shims would be needed to keep the cut open, since otherwise the cutting wire may break. The fully cut shaft may be strong and stable enough to stand unsupported on shims for Brent Bravo and Delta but some lateral support would be required for Brent Charlie. The weather window for the cutting and removal operation would be limited to 1.5 m significant wave height. Removing three legs in one season may not be possible because of weather restrictions.

Lifting could probably be accomplished using holes cut through the concrete walls in the lower part of the legs, to which large steel hooks could be attached. Thus, it was shown that theoretically it would be possible to cut and remove the legs. However, the technologies proposed need further development, although the contractors’ reports expressed confidence that it could be done. Shell has assessed the risk in terms of Potential Loss of Life (PLL) during cutting the legs and removing them to shore. This gave a PLL value higher than that normally acceptable for offshore oil and gas projects, but Shell has suggested that if the legs were to be cut the risks could be mitigated to an acceptable level, although no allowances for a reduction in risks were made in the Comparative Assessment.

Shell engaged a specialist consultant to assess the potential risk to users of the sea (primarily fishermen and shipping passing by the platforms). The leave in place solution (with appropriate navigational markers and safety zones in place) gave a risk in relation to shipping impact that Shell regards as acceptable. However, although the estimated probabilities of a collision may be low on a per annum basis, the consequences could be catastrophic and result in major injury and loss of life or serious marine pollution. In addition, the estimates require assumptions about the future volume of shipping activity, the routes to be used, the statistical distribution of deviations from the planned routes, and the efficacy of avoidance measures. These must all be estimated into the future (several centuries). Shell responded very constructively to IRG comments and suggestions on this work and commissioned additional studies by the consultants that helped considerably to clarify the major issues concerning the probabilities of rare extreme events. Nevertheless, the IRG considers that extrapolation of current and expected activity is uncertain, and is really only credible for the short term (say the next few decades). The risks become extremely uncertain for the longer term, with possible errors of several orders of magnitude, depending on the assumptions made concerning unknown future situations. The problems are exacerbated by uncertainty about the rate and mode of degradation of the structures. The evidence base for assessing that the long-term legacy risk to users of the sea is acceptably low is therefore very poor, as both the probability and the consequence of future collisions are essentially unquantifiable. There is moreover a fundamental difficulty in balancing the short-term operational risk to workers and the long-term legacy risk to users of the sea. The latter cannot be reliably quantified, and so does not
provide an adequate basis for any decision on whether or not to cut or leave the legs, which needs to be taken on more general grounds.

Shell has subsequently proposed that the risks should be monitored and regularly re-evaluated to enable decisions to be taken on the need for any further mitigation measures. However, while various options for additional mitigation of the risk may be applicable, such a re-assessment does not guarantee that corrective action, potentially involving structures that have become seriously unstable, will be feasible when it is needed. Moreover, the policy and regulatory requirements (either UK, IMO or OSPAR) may change in the future and require further action. The IRG therefore concludes that it is likely that the legs may need to be cut at some future time, and that adequate provision for this eventuality should be made as part of the decommissioning programme.

The IRG has read and assessed the reports produced by the contractors and consultants for Shell and provided detailed criticisms where necessary. It has also assessed the rationale leading to the decision by Shell and confirms that so far as it can judge the scientific, engineering and other evidence used to reach the decision was soundly based, except for the long-term risk estimates relating to the legs up/legs down options. However, the IRG notes that all the risk estimates are unusually uncertain. The preference in the Comparative Assessment is highly dependent on technical feasibility, risk and cost considerations, and that the outcome involves a difficult judgement balancing the very uncertain and long-term low-level risk of potentially serious consequences for future shipping activities, against the significant but time-limited and more reliable estimates of risks to the workforce.

4.2 Contaminants & Modelling

4.2.1 Surveys (Marine & Sea Bed)

Sea bed surveys describing the environmental conditions across the Brent Field were made in 1977, 1986, 1990, 2006, 2007 and 2015. The 2007 surveys were done by Gardline. The reports covering the conditions around all platforms including Brent South were reviewed by the IRG. The 2015 surveys by Fugro repeated where possible the 2007 stations that were outwith 100m of all the platforms. The reports from Brent Alpha, Delta and South were available to the IRG and have been reviewed. The sampling strategy was essentially the same in these surveys. The sampling campaigns cover grab samples from 10-20 sea bed sediment stations at distances from 100 to 2500 m from each installation and from four reference stations further away. Also box core, piston core and ROV push core samples were analysed from the sea bed cuttings piles at most platforms. Furthermore, a sampling survey of the cell-top cuttings at Brent Charlie was undertaken in 2011. In 2016, using the Brent Delta platform based ROV, samples were also taken from the top 70 cm (max) of the drill cuttings located on the cell tops, in one tri-cell and on the seabed at the base of the GBS. A repeat of the Brent Charlie survey of the cell-top and of stations near to the GBS has been postponed to a later date, closer to the commencement of decommissioning activities for this platform.

The analytical programme for the sea bed samples covered particle size distribution, total hydrocarbons, aliphatic and aromatic hydrocarbon groups, alkyl phenols, PCBs, metals, organic tin, radioactivity, and macrofauna composition. The cuttings samples were analysed for the same chemical parameters as well as particle size distribution, shear strength, density, water content and hydrocarbon leach rate. The surveys followed standard procedures for this type of studies, and the reports essentially had the same structure. The IRG stated that the methods used for the chemical analyses and data evaluation procedures were in some cases either not appropriate or not optimal, but in general found the quality of the work to be very good. The reports give a reasonably good description of the sea bed conditions, although the 2007 survey was less complete for the benthic fauna than for chemical conditions. The IRG made a number of specific suggestions for improvements to the sampling and analytical protocols and methods that were discussed extensively with Shell and most of these were used as the basis for modified procedures for later surveys.
When reviewing the 2007 survey reports, the IRG also expressed its concern that information on the deeper layers of drill cuttings on the sea bed was absent due to the fact that box and piston cores were taken outside the physical edge of the pile. In 2015 core samples were taken inside the perimeter of the cuttings piles at Brent Delta and South, and those at Brent South succeeded in penetrating through the pile and into the sea bed. The cores from Delta also reached pile layers containing old cuttings drilled with diesel-based mud. Drilling history spreadsheets, which were made available to the IRG, suggested that the 40-70 cm long cores had reached what can be expected to be the more contaminated layers of the pile. Hence, the IRG considers the data obtained on drill cuttings contamination to form an incomplete but nevertheless sufficiently representative basis for modelling of the drill cuttings fate.

The 2007 benthic survey described a general decrease in total hydrocarbon (THC) content with distance from the platforms. In 2015, THC levels exceeding 50 mg/kg (the OSPAR limit for effects on the benthic fauna) were restricted to stations out to 300 m distance. Subtle negative impact on the sediment fauna diversity was seen at some of the stations 300 m or closer to the installations (no impact around Brent South). These conditions are in line with the benthic conditions found around Norwegian installations of similar age, drilling history, water depth, and latitude.

Shell announced that a synthesis report discussing the analytical data in more detail and putting the survey data in a wider geographical and historical perspective would be prepared. As part of this, the IRG received a report giving a historical account of the environmental conditions for Brent Delta that showed a decrease in contamination with time at the feather edge of the pile. The rate of decrease is likely to be slower where the THC contents and the thickness of the cuttings pile increase towards the platform. The development at Brent Delta is likely to be seen at the other platforms as well. The IRG has not seen the synthesis report of the environmental status at the Brent field (incorporating the 2015 & 2016 surveys) which it understands will be issued later in 2017.

The IRG has read and assessed the reports produced by the contractors and consultants for Shell and provided detailed criticisms where necessary. It confirms that the scientific information available is sufficient to characterize the baseline environmental conditions near the surface of the sea bed prior to decommissioning adequately.

4.2.2 Drill Cuttings Inventory (Sea Bed, Cell Tops & Tri-cells)

Drill cuttings are rock fragments from the drilling operations, containing remnants of residues from the drilling mud. The base fluids in drilling muds used over time are either sea water, water based mud (WBM) or organic phase fluids (OPF) with the organic phase comprising oil (diesel- and low-aromatic oil-based muds, OBM) and synthetic organic fluids such as esters, ethers, olefins or vegetable oil (synthetic-based muds, SBM). Drill cuttings were discharged at all Brent installations. Discharge to the sea of drill cuttings with more than 1% organic phase fluids was terminated under OSPAR Decision 2000/3, although Shell had already stopped the discharge of cuttings with more than 1% organic phase fluid at Brent in 1998. Technology for cleaning of OBM cuttings offshore to less than 1% oil was later developed (e.g. thermal cleanings, TCC) and discharge of such cuttings was taken up again.

Cuttings are present underneath Brent Alpha and at Brent South and around and on top of the storage cells of all three GBS, most likely also in all the tri-cells and in the drilling legs (mostly uncontaminated cuttings from top-hole drilling) at Brent Bravo and Brent Delta. Brent Charlie does not have tri-cells open to the sea or drilling legs. The Shell best estimate of present cuttings volumes outside and inside the platforms amounts to ca. 60,000 m³, as specified in Table 1 [after ref 9].
Table 1. Drill cuttings inventory related to the platforms (all estimates in m$^3$) [ref 9]. Estimates of the material in the drilling legs of Brent Bravo and Delta are shown in Table 2 together with the cell contents.

<table>
<thead>
<tr>
<th>Platform</th>
<th>Sea bed</th>
<th>Cell top</th>
<th>Tri-cells (estimated)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brent Alpha</td>
<td>6,300</td>
<td>0</td>
<td>0</td>
<td>6,300</td>
</tr>
<tr>
<td>Brent Bravo</td>
<td>5,300</td>
<td>1,887</td>
<td>12,039</td>
<td>19,226</td>
</tr>
<tr>
<td>Brent Charlie</td>
<td>4,922</td>
<td>7,735</td>
<td>0</td>
<td>12,657</td>
</tr>
<tr>
<td>Brent Delta</td>
<td>2,230</td>
<td>3,790</td>
<td>14,733</td>
<td>20,753</td>
</tr>
<tr>
<td>Brent South</td>
<td>2,166</td>
<td>0</td>
<td>0</td>
<td>2,166</td>
</tr>
<tr>
<td><strong>Sum all Platforms</strong></td>
<td>20,918</td>
<td>13,412</td>
<td>26,772</td>
<td>61,102</td>
</tr>
</tbody>
</table>

Although the cuttings volumes estimated from recent survey data are uncertain, they are (with the exception of Brent South) significantly lower than estimates based on historical drilling records. Data presented in the Drill Cuttings TD [ref 9] suggest that about 60% of the total volumes of cuttings produced from drilling at the Brent field could initially not be accounted for, until cuttings in the tri-cells were considered. There may be several reasons for this, e.g. not all cuttings produced were discharged to the sea, cuttings were partly dispersed in the water and transported away from the pile, gradual consolidation of the pile material and episodic disturbance, re-suspension and erosion from the piles. Furthermore, for Bravo and Delta up to 82-94% of the cuttings not accounted for may be present in the tri-cells. The Environmental Statement estimates that the cuttings at Brent contain a total of 10,422 tonnes of oil, of which about half is in the tri-cells. [ref 12] In comparison, the cell sediments are assumed to contain a total of about 11,000 tonnes of oil (Table 3), and the attic oil in Brent Bravo and Delta, to be removed before decommissioning, amounts to 12,000-14,000 tonnes. [ref 12]

In 2007 the cuttings piles close to the platforms had THC levels up to 10%, i.e. close to the former regulatory limit for discharge of oil-based cuttings to the sea. The results of the 2015 survey at Delta suggest contents around 5%, but there are few available data. The survey of the cell top cuttings at Charlie in 2011 gave THC contents in the range of 8-20%, but one sample contained as much as 33% THC by weight. The cell-top cuttings sampled in 2015 from Brent Delta had THC contents in the range of 6-9%. The samples obtained from the Brent Delta tri-cells in 2015 (only one cell sampled) had THC contents in the range of 1.6 to 4.3%.

Concentrations of metals (Cu, Pb, Cd, Ni, Zn, Cr, Hg, As, and Al) were in general above the OSPAR background levels in the cuttings material, but varied somewhat unsystematically between platforms and with depth within the piles. The levels in general decreased with distance from the platforms, and typically were below the OSPAR background levels at 25-500 m distance. Concentrations of polychlorinated biphenyls (PCB) and alkyl phenols (AP), and levels of radioactivity were in all cases at or below their respective limits of detection (LoD).

The IRG made a range of comments on several versions of the Drill Cuttings TD [ref 9] and the supporting technical reports. A major topic of concern was the reliability of the estimates of contaminant content in the sea bed, cell top, and tri-cell cuttings. The sampling only covered the upper layers of the deposits. At the time it was assumed that earlier discharges of OBM and SBM cuttings could have resulted in deeper layers being more contaminated and hence the sampling did not necessarily provide a complete description of the pile composition. However, as stated in section 4.2.1, the account of the drilling history at the Brent field suggests that the cores taken from the cuttings piles
are reasonably likely to have encountered the most heavily contaminated material in the pile, and thus that the input concentration of oil in the modelling therefore most likely represents a realistic worst case scenario.

The IRG has discussed the issue of obtaining deeper and more representative cuttings samples with Shell on numerous occasions, and considers that this would still be desirable when and where possible, to confirm that the indirect estimates that have been made are appropriate. The most practicable solution will probably be to conduct sampling when the topsides have been removed, facilitating the use of heavier ship-operated gear for coring through the piles.

The information available on the presence of cuttings in the tri-cells at Brent Bravo and Delta remains incomplete because of sampling difficulties. The tri-cells are open to the sea, but some are presently covered with debris and cell-top drill cuttings. The Drill Cuttings TD [ref 9] and the Environmental Statement [ref 12] present estimates of probable cuttings volume. Shell made an effort to survey the tri-cells at Brent Delta in 2015, and the ROV succeeded in obtaining two shallow core samples from one of the tri-cells. The chemical composition of these samples does not seem to differ significantly from that of the sea bed and cell top cuttings. While the tri-cell cuttings appear to resemble the sea bed cuttings in terms of type and content of contaminants, they are closer to the Brent C cell-top cuttings or cell sediments in terms of their release scenario once the caissons collapse.

4.2.3 Drill Cuttings: Fate Modelling

Historical data demonstrate a substantial reduction in cuttings pile footprint, height and volume over the period 1997 to 2007 at all Brent installations (see Section 4.2.1), but the future fate of the drill cuttings can only be predicted by mathematical modelling, since the cuttings piles are expected to persist for much longer than the timescale for experimentation and observation. The model used by the contractors is PROTEUS, originally developed as part of the UKOOA Drill Cuttings Initiative 1999-2004 to predict the erosion and spreading of cuttings piles and the likely contamination levels in both the sea bed and the water column [ref 10]. The model has been used occasionally since then, but there appears to have been little or no subsequent development of it since the end of the JIP, and so far as the IRG is aware, there has been no work to refine or update the parameters or algorithms on which it relies, which during the JIP were recognized as being quite uncertain in some cases. The Scientific Review Group (SRG) for the JIP recognised that modelling the fate of cuttings was a difficult task in that

a) The algorithms used are simplifications that represent complex physical, chemical, and biological processes.

b) The parameters needed to characterise the properties of cuttings piles vary from pile to pile and in a particular case are difficult to determine accurately, so the choices that have to be made are uncertain.

c) There are few or no long-term data available with which to check model validity.

The JIP SRG concluded that the model predictions can therefore only be indicative, but in the absence of an alternative the model has nevertheless been used commercially. For the Brent Decommissioning Programme, Shell and its contractors have adopted it both for drill cuttings on the sea bed (Brent Alpha and Charlie) and on the GBS cell tops (Brent Charlie). Because of the many uncertainties the sensitivity of the predictions was tested by using a range of parameters around the “most likely” value for each principal variable, requiring many runs of the model.

The IRG reviewed a large number of reports on the fate modelling of drill cuttings and storage cell water and sediments and made many comments as well as some constructive suggestions. Drill cuttings fate modelling was based on data from Brent Alpha and Brent Charlie having the largest volumes of sea bed and cell top cuttings (Table 1). The model predictions suggest that undisturbed cuttings are likely to erode and spread only very slowly, with a 40-50% loss of cuttings volume and oil content after 1000 years. The predicted area persistence over 1000 years was far less than the OSPAR threshold of 500
km² yrs for all cuttings piles, and judicious extrapolation of the model results extending to 250,000 years still indicate full compliance with the OSPAR threshold. In most cases, the predicted oil release rate did not exceed the OSPAR threshold of 10 tonnes/yr. For Brent Charlie, the original modelling exercise gave a maximum release rate from the combined sea bed and cell top cuttings of 8.9 tonnes/yr, whereas remodelling with the highest measured cell top THC level (333,000 mg/kg) estimated the corresponding loss rate to be 14-16 tonnes/yr, remaining above the OSPAR threshold for about 30 years. Shell therefore carried out a full CA for the cell top drill cuttings at Brent Charlie which was presented in the final version of the Drill Cuttings TD. [ref 9]

It has been estimated that there may be about 12,500 and 13,500 m³ of drill cuttings in the tri-cells of Brent Bravo and Brent Delta, respectively. While Brent Bravo and Brent Delta remain structurally sound prior to the collapse of the GBS cells, the flow of water across the tops of the tri-cells will give little erosion or weathering of the contained cuttings. In this pre-collapse situation, Shell has suggested that the oil release rate estimated for the sea bed cuttings piles and used in their modelling can be applied to the tri-cell cuttings. The total tri-cell area open to the sea is very small (360 m² for both BB and BD) compared with the sea bed cuttings piles. The oil release rate and the area persistence (for a THC content greater than 50 mg/kg) are therefore many times below the OSPAR thresholds. However, once the GBS cells collapse the cuttings may spill as a cascade into the sea from a maximum height of 60 m above the sea bed. Shell has made quantitative comparisons of this release with the long-term fate of the cutting piles on the sea bed, human disturbance of cell top cuttings and the cell sediment static/dynamic release scenarios. The effect of tri-cell drill cuttings release is probably closest to that of the Brent C cell top drill cutting disturbance, but possibly more extreme because there is a greater volume of tri-cell cuttings. The environmental impacts of release are likely to be of a broadly similar magnitude. However, the oil release rates and persistence after collapse of the cells have not been modelled directly.

Despite the many uncertainties the IRG considered that the results do provide a sufficient basis for the CA process, but the IRG agrees with the former Drill Cuttings JIP Scientific Review Group that the modelling results should be regarded as indicative rather than definitive.

4.2.4 GBS Cell and Leg Contents

Besides the drill cuttings on the sea bed around the Brent Field installations and on the GBS storage cells, the residual materials in the storage cells and in the legs of the three GBS are of major concern regarding possible environmental pollution. No provisions had been made during construction of the GBS for inspection of the cell contents at the time of decommissioning, and inspection of the bottom of the GBS legs at this stage turned out to be very difficult.

The GBS cells have been used for storage of produced oil, water and fuel, though to different extents on Brent Bravo, Charlie and Delta; they were also found to be more effective for removing sand from the produced oil than the separators on top of the platforms. Brent Delta was the first platform in line for decommissioning, so attempts to assess the amount and nature of residual materials in the cells has mostly concentrated on this platform. When it became clear that access to the cells was impossible through the existing pipework, surrogate samples were collected and analysed. These comprised separator samples taken during ongoing production on the platforms and samples from storage facilities on land (Sullom Voe) and off shore (Brent Spar). The analysis of these samples, together with an assessment of the production history, led to estimates of the amount of oil-contaminated water and sediment and their chemical composition in the cells.

During the oil producing phase of production, the cells were always operated in a completely filled mode, i.e. oil exported was replaced by seawater, and when produced oil was filled into the cells, the equivalent volume of water was released into the sea. At the time of decommissioning, the cells are filled with water and in some cases a small volume of “attic oil”.
The storage cells of Brent Delta contain residual “attic oil” that could not be recovered through the existing pipework because of their physical arrangement below the top of some of the dome-shaped cells, together with a high viscosity emulsion of water and oil that has accumulated at the boundary of the attic oil and the water phase. All attic oil was removed from the Brent Bravo storage cells, but they may still contain some interphase material, which was not recoverable through the existing pipework. Removal of attic oil though existing pipework may also be possible with Brent Charlie. While the amount of the attic oil could be estimated from the topography of the cells, there was no need to determine its chemical composition since Shell was committed to comply with the BEIS/DECC requirement for complete removal of attic oil and interface material.

Following a large and costly technical development of appropriate sampling tools, Shell succeeded in gaining access to three of the sixteen Brent Delta storage cells through small-diameter holes drilled through the cell domes, sampled the cell water and sediment phases, and obtained information on sediment surface topography and thickness using a 3D sonar device. Detailed physical, chemical and biological analyses were made on the sediment samples. The sediment solids proved to be predominantly sand with a small silt and clay fraction varying from 5-20% between cells. The sediments on average are composed of broadly equal proportions by volume of oil, water and solids, but there are marked variations between the cells from 39% to 13% of oil by volume. Although there is some uncertainty concerning the analyses, the THC contents appear to vary from 134,000 to 168,000 mg/kg for the sediment between the cell samples. The measured average contents of contaminants in the cell samples were similar to those that had been previously estimated from the surrogate samples but the average BTEX (sum of the monoaromatic compounds benzene, toluene, ethylbenzene, and xylene) and THC values were higher by 10% and 28%, respectively, in the analysed samples. Several of the other contaminants were much lower in concentration than the original surrogate estimates. The THC analyses in the cell water showed a much greater variation between cells with a range from 30 to 1081 mg/l, which was assumed to be related to the production history.

Despite the very considerable effort required to obtain and analyse the samples, the information gained from the sampling programme is limited, and thus may not be fully representative of the remaining cells or of those of the other platforms because

- Only three cells on one of the platforms, out of the many cells on three platforms, have been sampled.
- The sediment sampler penetrated only the top few decimetres of the approximately four metres thick sediment layer.
- The sediment material was disturbed during sampling and the estimates of certain physical properties are unreliable.
- Samples were comingled prior to analysis so that no vertical profile information became available.
- There is a marked variation in the concentrations of some of the contaminants in the sediment and particularly in the water samples.
- Some of the samples may have become contaminated during transit of the sampler through the attic oil/interphase material layers.

Table 2 shows the estimated total amounts of material likely to be left in place in the GBS using all available information at the time of decommissioning. Table 3 shows the estimated amount of oil in these materials. The attic oil and the interface material will be completely removed before the platforms will finally be abandoned and become exposed to natural degradation, and thus are not included in the tables.

On the basis of desktop studies, and sampling and analysis it is known that there is also oil-contaminated material at the bottom of the Delta drilling leg and Delta mini-cell annulus, and it is
assumed to be present at the Bravo GBS also. Brent Charlie due to its design does not have drilling legs or a mini-cell. As shown in Table 2, the estimated volumes of contaminated material are small. Mini-cell sampling of Brent Bravo is planned but the outcome is likely to be similar to that for Brent Delta, as has been assumed in Shell’s Decommissioning Programmes. As the oil-contaminated material represents cuttings from top-hole drilling with water-based mud, the oil must have a different origin. Possibly, dip trays under some of the equipment located higher up in the leg may have over-filled and spilled into the bottom part of the leg. Alternatively, the oil contamination may be a result of over-filling of the storage cells and leaking through small holes in the water ballast lines that run through the mini-cell.

Table 2. Estimates of the materials left in place in the Brent GBS platforms [ref 7].

<table>
<thead>
<tr>
<th>Material</th>
<th>Bravo</th>
<th>Charlie</th>
<th>Delta</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oily water (m³)</td>
<td>163,840</td>
<td>311,667</td>
<td>163,040</td>
<td>638,547</td>
</tr>
<tr>
<td>Cell sediment (m³)</td>
<td>17,280</td>
<td>6,035</td>
<td>17,280</td>
<td>40,595</td>
</tr>
<tr>
<td>Mini-cell oily material (m³)</td>
<td>250</td>
<td>0</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>Drilling leg oily material (m³)</td>
<td>2,000</td>
<td>0</td>
<td>2,000</td>
<td>4,000</td>
</tr>
</tbody>
</table>

Table 3. Estimates of oil in water and sediment left in place in the Brent GBS platforms [ref 7].

<table>
<thead>
<tr>
<th>Material</th>
<th>Bravo³</th>
<th>Charlie</th>
<th>Delta</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil within the water (tonnes)¹</td>
<td>68</td>
<td>130</td>
<td>68</td>
<td>267</td>
</tr>
<tr>
<td>Oil within the sediment (tonnes)²</td>
<td>4,800</td>
<td>1,676</td>
<td>4,800</td>
<td>11,276</td>
</tr>
<tr>
<td>Oil within drilling leg contaminated material (tonnes)</td>
<td>23</td>
<td>0</td>
<td>23</td>
<td>46</td>
</tr>
<tr>
<td>Oil within mini-cell annulus oily slurry (tonnes)</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

¹Calculation based on an average hydrocarbon concentration of 417 mg/l.
²Calculation based on an average oil content in the sediment of 25% and an oil density of 0.9 g/cm³.
³Assumed to be the same as in Brent Delta.

The analytical results for the water and sediment varied considerably among the three Brent Delta cells (9, 17 and 18) for some of the parameters. The most abundant organic components in the water phase were total petroleum hydrocarbons (30-1100 mg/l), organic acids (3-9 mg/l) and benzene (2-7 mg/l); the concentrations of key polycyclic aromatic hydrocarbons (PAHs) were in the range of a few µg/l or lower. Zinc was the most abundant heavy metal in the water (<1200 µg/l), followed by copper (<160 µg/l), nickel (<150 µg/l), chromium (<12-170 µg/l), lead and arsenic (both <9 µg/l) and mercury (1-3 µg/l). During the attic oil removal additional water samples were taken from cells 6, 7 and 10, all of them yielded low hydrocarbon concentrations upon analysis. Comparison with the bulk de-oiling history of the cells suggests that cells de-oiled in 2005 and 2015 are likely to have low residual hydrocarbon concentrations in the water phase (e.g. Cells 6, 7, 9 and 10), whereas cells de-oiled in 2009 are likely to have higher hydrocarbon concentrations (e.g. Cells 17 and 18).
The results of the analysis of the sediments collected from Cells 9, 17 and 18 confirmed that the samples are a mixture of sand particles, water and oil. The water content was higher than originally assumed but this may be due to the fact that the sediment samples were collected from the less compacted surface layer of the sediment. The main contaminants are organic compounds originating from the hydrocarbons processed through the storage cells or the added chemicals. The Cell 9 sediment contains about 39% oil and the same amount of water together with 22% sand, whereas the oil content is lower at 22% and 13% in Cells 17 and 18 together with 51% and 57% water, respectively. The particle size distributions are centred on the range 100 μm to 400 μm; as with some other parameters, Cell 9 exhibits a slightly different particle size distribution with a small shift towards smaller particles. Comparison of the analytical results obtained from the sediment samples with the initial assumptions from desktop studies and surrogate samples revealed that the concentrations of most of the chemicals were lower or much lower than previously assumed. The average concentrations of BTEX and total hydrocarbons were, however, 10% and 28% higher, respectively, than the estimated values.

4.2.4.1 Cell and Leg Content Management

After removal of the topsides and in the absence of drawdown, small access holes will be drilled in the dome of each oil storage cell on Brent Delta from a vessel. Attic oil and interphase material will be recovered and ultimately transported by ship to land and treated and/or reused. For Brent Charlie it may be possible to extract the attic oil using the existing pipework, however, this extraction method has still to be verified.

For the management of cell water and sediment, a short-list of five options was considered for Comparative Analysis:

- Option 1: Recover and re-inject
- Option 2: Recover to shore for treatment
- Option 3: Leave in place and cap
- Option 4: Leave in place with monitored natural attenuation (MNA)
- Option 5: Leave in place untreated.

A range of extraction options for the cell sediments were explored by Shell. Some of these considered access while the topsides were in place. The difficulty here is that the “drawdown” (i.e. reduction of hydrostatic pressure in the cells) must be maintained while the platform is still manned. Under these circumstances the studies show that the only feasible means of access is through a small-diameter hole cut through the top of the cells. This approach is particularly attractive in that the attic oil will eventually be extracted from Delta and possibly Charlie in this way. A number of “pipe in pipe” systems to liquefy and pump out the cell sediment were investigated with access being through small holes cut in the cell domes. None of these were found to be viable. However, once the topsides have been removed and drawdown is no longer required it should be possible to cut a much larger hole in the cell tops and extract the cell sediment using more conventional dredging techniques.

**Option 1: Recover and re-inject.** After removal of the attic oil and interphase material through a small hole in the top of each cell, the cells would be dosed with H₂S scavenger to reduce the H₂S concentration of the fluids that would have to be handled on a vessel. The water phase would then be pumped out through the small access hole and replaced by seawater through the water ballast lines. A large access hole would be created with suitable arrangements for preventing the water phase from escaping to sea. This access would allow subsea dredging equipment to be deployed into the cell to recover the sediment. A sediment slurry would be created and pumped to the deck of a support vessel, then transferred to a tanker for temporary storage. The full tanker would transport the slurry to a newly drilled injection well.

**Option 2: Recover to shore and treatment.** The entire contents of the GBS storage cells would be completely removed as described for Option 1, and the recovered slurry would be disposed of onshore.
**Option 3: Leave in place and cap.** A physical barrier (“cap”) would be created on top of the sediment in each cell to minimise the potential dispersion of sediment when the GBS collapse. The exact method of executing this option would depend on the nature and amount of capping material that was deployed, and this would determine the deployment mechanism.

**Option 4: Leave in place with monitored natural attenuation (MNA).** A variety of chemicals would be injected into the cells to promote *in situ* natural biodegradation of the hydrocarbons. The reduction in hydrocarbon content would contribute to reducing the environmental impact of the eventual exposure or release of the cell contents when the GBS collapse.

**Option 5: Leave in place untreated.** Both the water phase and the sediment phase would be left in place in the cells, untreated, after the removal of the attic oil and interphase material.

From September 2011 to June 2013 Shell completed a total of five workshops with a group of 16 stakeholders called the Management Stakeholder Task Group (CMSTG; cf. Section 3.4.1) in which the advantages and disadvantages of the options were examined and discussed, and the performances of the options assessed against a range of criteria. The work of the CMSTG was facilitated by the independent consultant Catalyze, with the Shell team providing data and information as requested and available before the Cell Survey Project. To manage the data and assessment, Catalyze used the software HiView3 to permit the CMSTG to build and then interrogate a Multi-Criteria Decision Analysis (MCDA) model. The CMSTG identified the criteria with which they wished to assess the performance of the options, scored the performances of the options in each criterion, and weighted the criteria relative to each other. Catalyze summarised the findings of the CMSTG work as follows [cited from ref 11]:

- “Option 5 ‘Leave in place’, performs well on minimising the use of natural resources, and in other factors including safety and technology readiness, but in the final model these factors are not enough to compensate for concerns over the long-term effects on the marine environment, and the poor contribution to knowledge gained. However, under certain scenarios, this does become the preferred option.
- Option 4 ‘Leave in place with MNA’, is not the preferred option in any of the scenarios examined.
- Option 3 ‘Leave in place capped’, is on balance found to be the best performing option, but only by a small margin. A significant factor here is that capping is assumed to mitigate the long-term impact to the marine environment. However it would not reduce the quantity of hydrocarbons released although it would be likely to extend the duration of the release somewhat. Overall it is unlikely to result in a big enough advantage over the LIP option compared to the cost and effort of providing and delivering the capping material.
- Option 2 ‘Vessel to onshore’, is constrained by the use of natural resources including landfill, coupled with perceived risks to the marine environment during operations. However, this does become the preferred option under certain circumstances.
- Option 1 ‘Remove and re-inject’, is a close second in the final model, removing long-term impact to the marine environment while using limited [amounts] of natural resources, and avoiding the use of landfill. However, significant concerns over this option have been raised, a point not covered explicitly in the model.”

Although not discussed specifically by the CMSTG, the same criteria and options would apply to the oil-contaminated residual materials in the GBS drilling legs and the mini-cell annulus.

Shell used the results of the CMSTG work to inform their own consideration of the performances of the technically feasible options for the cell contents. The Shell Comparative Assessment came to the conclusion that the preferred option is to leave the water and sediment in the cells and in the legs in
place and untreated. The consequence will be the release of the material to the environment when the concrete of the cells or the legs has degraded naturally or when falling parts of degraded legs destroy the caissons.

Contaminants in the water phase are then likely to be rapidly dispersed through dilution and biodegraded, and are likely to cause impacts that would be local and transient (see ES and related modelling). The solid materials in the GBS are not likely to be released or exposed in the marine environment until the cells are significantly damaged in the future. Prior to release, no environmental impact is expected in the surrounding marine environment from these materials. Given these exposure scenarios, Shell does not propose any environmental monitoring programme related to the GBS contents. The IRG considers that further cell sediment sampling during decommissioning would nevertheless be desirable, to provide continuing assurance to BEIS and other stakeholders that the estimates made of the quantities and composition of the cell contents remain valid.

The IRG reviewed and commented on all of the contractors’ reports on cell access, cell sediment removal, cell contents and their management, and is satisfied that a sufficiently wide range of options have been examined and that the decisions made by Shell have a sound evidence base.

4.2.4.2 Re-Injection

One option for disposal of the cell contents considered in some detail was sub-surface re-injection. This technique is used by Shell and other operators to dispose of drill cuttings and other waste materials. Shell undertook a number of detailed studies examining the technical feasibility of re-injection. Shell, from its own data and experience, made geological assessments at the Brent Bravo, Charlie and Delta sites and reviewed the suitability of existing Brent well bores and newly drill wells, both at and remote from the three platforms.

Studies were based on cell sediment consisting of 1/3 solids, 1/3 oil and 1/3 liquid and a disposal volume of 17,000 m³ for each platform, which, with a 1:10 dilution, gave a total waste volume of 170,000 m³. The requirement to inject the total liquid content of the cells (including the large volume of oily water) was also considered. Two potential geological formations were examined. These were the deep Brent/Statfjord hydrocarbon reservoir and the shallower Frigg/Skafe sands. A review of worldwide practices showed that successful waste injection is mostly into shallower strata of the latter type. Previous attempts to inject drill cuttings into the Frigg/Skafe strata had been successful. The risk of injecting into the Frigg/Skafe sands is a breakthrough to the sea bed, but it was considered that this could be avoided by robust design and monitoring. Detailed studies of the use of existing or new Brent Delta platform wells concluded that they were unsuitable.

Shell’s conclusion was that the most reliable scheme to meet the waste capacity, injection rate and well construction requirements would be to drill new vertical wells into the Frigg/Skafe sands located at a sufficient distance from the platforms such that fractures created during injection would not extend out to the existing platform wells.

The IRG assessed the reports produced by Shell and its contractors and considered the above conclusion to be soundly based.

4.2.4.3 Cell Sediment Modelling

If the cell contents are not removed (i.e. for the “leave in place”, MNA or capping options) the cell water and sediment will at some stage be released to the sea floor or the water column, when the GBS cells are breached or eventually collapse. Their fate therefore needs to be considered.
The mode of cell collapse and release is extremely uncertain (see Section 4.1.3) as is the quantity and nature of the contamination that is likely to result. Moreover, there is no numerical model available that has been specifically designed for evaluating the fate of cell contents. Shell and its contractors have therefore used a slightly modified version of the PROTEUS model (designed for cuttings piles, see Section 4.2.3), making various assumptions to arrive at approximate estimates.

Shell considered two scenarios:

- The cell sediment on release from a number of cells forms a conical pile on the sea bed.
- Cell sediment on the rapid collapse of a number of cells cascades into the water column with some sediment being transported in the water and some settling onto the sea floor.

A range of assumptions for a number of the input parameters (and combinations thereof) where these are particularly uncertain were also considered.

The IRG reviewed many modelling reports and had some interaction with the contractors in an attempt to ensure that the issues were thoroughly explored and adequately approximated, because the modelling of the fate of cell contents after their possible release caused particular difficulties. For the modelling of cell sediment release based on an assumed sediment cone on the sea bed there were several major changes in results presented in different revisions of the same report even though the parameters being used in the scenario being modelled appeared not to have been changed. These issues now appear to have been resolved. The results indicate that the conical pile of sediment on the sea floor may be a credible ‘worst case’ in terms of volume of cell sediment released and long term persistence, but is not necessarily the worst case for environmental impact. Modelling of cell sediment released at a higher level some tens of metres above the sea bed directly into the water column suggested a larger footprint of adverse sea bed contamination than from the conical pile scenario. The IRG felt that a satisfactory comparison of the two scenarios had initially not been made. It appears from the analysis in the EIA/ES that for the sea bed cone scenario the levels of contamination and persistence are expected to be similar to those resulting from the drill cuttings.

Although the modelling results can only be regarded as order-of-magnitude estimates, they are considered to be adequate as a basis for assessing the likely environmental impact of the cell sediment release. The estimated maximum distance from the GBS receiving more than 10 mm of deposited cell sediment (a likely PNEC for hyper-sedimentation) for any modelling scenario was around 2000 m and the maximum extent of PEC:PNEC>1 for THC was 3500 m. This is in line with the maximum distances where effects on the fauna were seen during the era of discharges of oil contaminated drill cuttings. Overall the modelling strongly indicates that the environmental effects from the release of cell sediments will be local, although the adverse impacts on the sea bed may persist for several decades. There is however no reason to expect that the release of the cell sediments will have regional or population effects on benthic organisms in the area.

The solids in the cell sediment are predominantly composed of sand size particles. Some studies have shown the oil mixed with such material may be released as free oil when such sediments are disturbed. A substantial amount of free oil (possibly as much as 400 m³ if three or more cells collapsed at the same time) could therefore be released as the cells collapse. A modelling study was carried out to examine this possible situation. The model only considered the release of a rather small quantity of oil (20 m³ from each of the 3 platforms). The impacts of this on the marine environment, estimated as sea surface contamination and beaching of oil, appeared to be small but there is uncertainty as to what the impact would be if the releases were scaled up to a larger possible release volume. This has not been assessed in the TD or ES

**4.2.4.4 Cell Water Release**
The IRG has reviewed several reports presenting the results from the PROTEUS model of cell water release and expressed its concerns regarding the results and interpretation. The initial choice of PNEC (potential no effects concentrations) values for the various contaminants was questioned, in particular that PNECs were changed, some by orders of magnitude, in the transition from the original Phase 1 to the Phase 2 modelling exercise, without satisfactory explanation or justification. This was, however, resolved as described below. Furthermore, the determination of impact zones was based on chronic PNEC values, although estimated exposure duration to contaminant concentrations above the PNEC was in the range of a few days at most. This makes the use of acute PNEC values more appropriate, which would most likely decrease the impact zone. Following discussion with the IRG, agreed PNEC values for oil in water were adopted for the later work used to inform the TD and ES. Also, the cell water dilution pattern after release showed some surprising features that reduce the overall confidence in the modelling of the cell water plume behaviour.

As for cell sediments the results of cell water dispersion modelling is regarded as indicative, but adequate as a basis for assessing the likely environmental impact. The estimated maximum distance in the water column encountering a PEC:PNEC>1 for THC was 17,000 m and the maximum time until PEC:PNEC<1 was 173 hours (similar or less for other contaminants). The short exposure time leads the IRG to suggest that the maximum distance with real risk of effect on pelagic organisms will be in the order of 2000 m and that the effects will be short term.

The IRG also reviewed the reports from two other cell content modelling exercises, one using the DNV-GL DREAM (Dose-Related Risk and Effects Assessment Model) model, and one using the SINTEF OSCAR (Oil Spill Contingency And Response) model. The DREAM model was run as a cross-check of the PROTEUS model outputs on cell water, but in the rather informal report of the DREAM exercise a detailed comparison was not presented or discussed. Shell stated that the intention was only to carry out a “sense check” against the corresponding PROTEUS model and that the DREAM document would not be used to support the DP, and the IRG found this response acceptable. The OSCAR model was used to describe the likely dispersion and fate of oil released with the cell water including landfall of oil in UK and Norway. The IRG found the OSCAR modelling interesting, and a useful check that the impacts of free oil from the cell water are likely to be minor and transient.

4.2.4.5 Fate of Cell Contents: Discussion

The IRG considers the PROTEUS and other modelling results to be indicative only, but on the basis of simple but probably more robust order-of-magnitude estimates the IRG accepts the main conclusion, as expressed in the ES risk assessment of cell water and sediment releases. This states that the release of cell water contaminants will cause “limited transient effects close to the release point” (more precisely contaminant levels exceeding chronic PNEC levels for each platform would be confined to an area of a few km² for a few days) and that “released amounts of bio-accumulating substances are too small to represent a threat on the regional level”. In the case of release of the cell sediments, the results are more uncertain because they depend on the release scenario, and because no fully appropriate model is available. However, the best available estimates from the modelling indicate that the area of sea floor significantly impacted (i.e. THC concentrations >50 mg/kg and thickness of settled cell material >1 mm) would probably be in the range of a few km² for each platform. Data from sea bed recovery after discharges of oil-based drill cuttings elsewhere suggest that full benthic fauna recovery from one such incidence will be in the range 5-10 years. Repeated releases as new cells are broken will probably not increase the areal extent of effects, but may retard overall benthic recovery. The spread of the deposited sediment on the sea bed following the dynamic release of sediment due to the collapse of one or more cells has not been modelled in the longer term. So some uncertainty as to the environmental impacts remains but the broad conclusions on the environmental impacts would probably not change significantly although the time scales of impacts may be extended.
The IRG has read and assessed the reports produced by Shell, its contractors and consultants and has provided detailed criticisms where necessary. It has also assessed the rationale leading to the decisions by Shell and confirms that so far as it can judge the scientific, engineering and other evidence used, whilst very uncertain especially in relation to long-term effects, appears to be adequate to reach the decisions made.

4.3 Pipelines

The pipelines were, in accordance with the DECC/BEIS Guidance Notes [ref 5], attributed to two categories, those which needed a full, detailed quantitative comparative assessment and those which had an easily discernible recommended decommissioning option and hence were subjected to a qualitative comparative assessment process.

It is proposed in the Brent Field Pipelines Decommissioning Technical Document [ref 18] that the qualitative pipelines (14 in total) will be mainly removed by reverse reeling or cut and lift (9 in number). Four were installed initially in trenches and will be left in the trenches. Finally one pipeline has over-trawlable rock dump and will be left in that condition.

For the quantitative pipelines (14 in number), one will be removed by cut and lift, all of the others will remain. Of these, eight will be trenched and backfilled, four will be mainly trenched and backfilled with some rock dumping. These proposals have been modified from earlier proposals that were mainly that Leave in Place (with remediation of remote ends with rock dumping) would have been recommended; since then, Shell has responded to concerns expressed by fishermen and changed to trenching. The remaining pipeline (the main oil export line) will be retrenched where possible. Where difficulties occur rock dumping will be used.

The area within a corridor of 200 m centred on the pipelines (i.e. 100 m either side) will be cleared of debris and the items recovered returned to shore for recycling or disposal onshore as appropriate. Following completion of the Brent decommissioning operations, the previous locations of the pipelines and the locations of any remaining sections of Brent pipelines will be part of the sea bed clearance survey. The frequency and number of subsequent structural and environmental surveys will be discussed and agreed with BEIS. Under current legislation and licensing arrangements, Shell will remain liable in perpetuity for any sections of pipelines remaining in the Field.

The IRG considers that the evidence base is sound and that the CA s have been done properly and the results support the proposed actions. However, it is also noticeable that the balance of advantage is small and so small differences in the input data can be magnified by the CA process.

Only the export line N0501 is expected to have FishSafe-recordable spans after decommissioning, and Shell are planning to remove these prior to trenching and rock dumping the rest of the pipeline. Spans can change with time becoming larger or smaller, as evidenced in the pipeline survey history of the other Brent pipelines. Shell will need to monitor pipelines for spans and act if necessary, and a programme of pipeline monitoring will be agreed with the regulator. Any spans that emerge will be removed or recorded on FishSafe and marked on charts through UKHO.

4.4 Environmental Impacts & Statement

The Environmental Impacts Assessment and the preparation of the Environmental Statement (ES) [ref 12] for the project were carried out for Shell by DNV and follow the well-established DNV-GL format for these products. This means that the ES includes discussion of some issues that are not strictly environmental (e.g. impacts on shipping and employment) and that are also assessed as part of the overall CA process. The IRG reviewed an early draft of the ES (R03) and made a large number of comments on it; the IRG is content that Shell and DNV-GL have reacted positively to these. The IRG
has subsequently reviewed several revised versions and has offered over 100 comments in total on these documents.

In general, the IRG is content that the ES provided a satisfactory assessment and overview of the environmental impacts of the various decommissioning options and that DNV-GL has evaluated the information provided by Shell and its contractors objectively and adequately, although the IRG considers that the cell content and drill cuttings scenarios modelled and the resulting model outputs could have been examined more critically. Environmental impact comparisons, for both the short and long term, between the static cone and the dynamic high level release of cell sediment have been made, stressing that the great majority of the larger footprint from the dynamic release is covered by less than 1 mm of cell sediment. However, it is primarily the actual area covered by thicker deposits that should be considered, and the footprint with >10 mm cell sediment and which has very high PEC /PNEC values is a factor 12 to 21 times larger in the dynamic than in the cone scenario, though nevertheless small [ref 21, Table 35].

The IRG notes that the cost estimates and assessments of safety risks have not been independently verified. However, DNV-GL was not responsible for evaluating the evolution and selection of options to be taken forward for the assessment. The IRG observes that the ES inevitably contains a large number of judgements, as to what is significant or not, that are at least partly subjective. The IRG is also concerned that the ES assumes perfect execution of the proposed work, and full compliance with the safety zones established, and takes account only of the minor inconvenience of these to fishing and shipping. It does not consider the human impact of accidents (although it does consider other human impacts such as employment). Although this may be common practice the IRG does not consider that it provides a fully balanced overview of all relevant outcomes. In addition DNV-GL do not appear to have challenged the validity of some potentially unreliable input data provided to them, as would be expected of a fully independent analysis.

The IRG notes that there are no generally recognised practical thresholds for acceptable levels of releases or persistence of THC or other pollutants that may affect biota in the water column, or sea bed sediments comparable to those that have been adopted for contaminants in drill cuttings. A joint effort by operators and regulators to develop such thresholds would facilitate the preparation of future environmental statements and could be initiated by considering (for example) whether and in what circumstances the accepted release rates and persistence threshold for cuttings-related material on the sea bed that is contaminated above a defined level might be more widely applicable, and/or what modifications might be appropriate.

4.5 Long-Term Issues: Monitoring & Legacy

If the Shell proposals, including the sought derogations, for decommissioning the Brent Field are approved, a number of structures and associated materials will remain in the marine environment once the decommissioning process is completed. These will include

- the Brent Alpha steel jacket footings;
- the concrete caissons and legs of the Brent Bravo, Charlie and Delta GBS;
- contaminated sediment and water within the cells of the GBS caissons;
- contaminated drill cuttings on the sea bed, cell tops and in the tri-cells;
- several pipelines.

Shell proposed to monitor these residual structures and remaining materials over time. The purpose of monitoring will be to check that the structural degradation is proceeding as expected, and ensure that there are no significant additional safety or environmental effects above those already modelled and assessed. If it emerges that adverse conditions arise either in the environment or to users of the sea it has been recognised that it may be necessary to take remedial action.
Detailed surveys of the sea bed to collect physical, chemical and biological data, both around the Brent Alpha and Delta platforms and the Brent South site and also extending well outside the areas contaminated by drill cuttings, were carried out in 2007, 2011 and 2015. Charlie celltops were not resurveyed in 2015 but the IRG understands that this will take place closer to the commencement of decommissioning activities for that platform. These surveys provided essential pre-decommissioning baseline data. Shell intends to repeat these survey procedures once decommissioning of the field and a debris sweep have been completed. Thereafter, the proposition is to conduct two surveys once decommissioning has been completed to ensure an adequate baseline and that subsequent recovery is being established. If and when a trend emerges, the frequency of future surveys may, following discussions with the regulating authority, be changed. The IRG is satisfied that a comprehensive range of parameters defining the present environmental condition of the sea bed was obtained during these surveys. Providing these high standards are repeated, the suggestions for future surveys are acceptable. However, it should be noted that due to restrictions on the survey vessels approaching the platforms, the nearest samples of drill cuttings from other than the surface layers could only be obtained at about 50 to 100 m from the platform. The drill cuttings at depth under or close to the platforms have not been sampled. Once field decommissioning is complete, it would therefore be desirable for an attempt to be made during the post-decommissioning survey to collect samples from the thickest section of the cuttings piles close to or at the platform. Similarly, except at Brent South, the core samples from the previous surveys have only penetrated to a limited depth, and it would be desirable for an attempt also to be made in the post-decommissioning survey to collect samples from the deeper parts of the cuttings piles, provided this can be done without undue expense or difficulty, in order to supplement the incomplete information already available.

Shell has proposed to undertake structural surveys of the “as left” conditions of the Brent Bravo, Charlie and Delta GBS and the Brent Alpha footings. It is unlikely that there will be any observable degradation of these structures over the next 20 years. Shell has therefore also proposed that it will discuss and agree with BEIS proposals on the type and frequency of surveys to be carried out in future. No indications are given in the Decommissioning Programmes document [ref 1] as to the nature or frequency of such surveys. The IRG considers that it would be informative and of interest to stakeholders to have, prior to consultation, some indication as to what is likely to be undertaken.

Shell engaged specialist consultants to estimate the safety risks to users of the sea from the GBS legs being left in place, their subsequent deterioration to just below sea level and their longer term deterioration leading to eventual total collapse. The IRG indicated to Shell that for a number of reasons the risk estimates that emerged from the analyses were very uncertain and may be over or underestimated possibly by one or several orders of magnitude. In the light of these extreme uncertainties Shell is now proposing, as part of its monitoring programme, to repeat the assessment of safety risk to users of the sea at regular intervals using the latest published data and new data on trends in fishing and commercial shipping activity. In this way a “rolling programme” of risk assessment would be established. Such a rolling programme would also take into account the changing condition of the GBS left in place on the sea bed. If any re-assessment showed that the level of risk was unacceptably high, Shell would consult with the authorities and users of the sea to consider what actions could or should be taken to mitigate the situation. The IRG welcomes this suggestion but notes that while various options for additional mitigation of the risk may be applicable, such a re-assessment does not guarantee that corrective action, potentially involving structures that have become seriously unstable, will be feasible when it is needed.

Shell proposed to leave a number of pipelines on the sea bed. Some of these are already buried and others will be trenched and buried or covered in rock fill. Some sections of buried pipelines may become exposed due to the movement of sea bed sediment. Erosion below the pipeline can lead to the development of an unsupported length of the pipe, called a “span”. Long and deep spans present a potential hazard to fishermen in that gear can be trapped. Shell has surveyed the pipelines and such spans are recorded in the FishSafe system. Presently, pipelines are surveyed regularly and any spans
judged hazardous are remediated if so required by the regulator. There will be a need for pipeline monitoring post-decommissioning, including the continuation of the span monitoring (see section 4.3).

The Decommissioning Programmes document provides a diagram covering a timescale extending from the present to 1000 years into the future and indicating, in broad terms, monitoring in relation to the collapse of structures or possible environmental issues which may arise. However, there is very little detail of the monitoring procedures given. There is a useful scoping diagram but a question inevitably arises in relation to responsibility for long-term monitoring and legacy issues. It is stated in the Decommissioning Programmes document that monitoring and any necessary maintenance or remediation responsibility for the structures and materials left on the sea bed remain with Shell and its co-venturers in perpetuity. For example, it may emerge in 30 or 50 years that the jacket footings are a greater risk to fishermen than at present and that it may be necessary to remove them, or after 150-200 years the tops of the GBS legs collapse to hang in a dangerous condition just below sea level and removal is considered necessary. If Shell were no longer to exist the responsibility would fall either to its partner operators, their successors or failing that to the Government.

4.6 Comparative Assessment Process

In accordance with DECC/BEIS guidance [ref 5], Shell has used a Comparative Assessment (CA) procedure to evaluate the various options for decommissioning all main components of the Brent installations. Individual Technical Documents (TD) address all the main components, and there is a CA within each document. The CA procedure has been supported by a fairly elaborate semi-quantitative Multi-Criterion Decision Analysis (MCDA) facilitated by specialist consultants. The results of the MCDA were used to inform but not to determine the outcome of the CAs and the selection of the preferred options. The IRG has reviewed several versions of the Brent Field Decommissioning Comparative Assessment Procedure [ref 20] dealing with the CA procedure [see also ref 13] and discussed the merits, disadvantages and practicalities of utilising MCDA with Shell staff on numerous occasions. In principle, MCDA (see e.g. Yoon & Huang 1995 [ref 15]) for a brief account) is the right tool for the job of conducting a CA. However, in practice there can be considerable difficulties, particularly where the criteria are incommensurable (i.e. one is comparing apples and oranges) or the estimates of the scores for some criteria are seriously uncertain. The weights to be attached to the scores for the various criteria can also be very difficult to determine and may be controversial among stakeholders.

In the procedure used by Shell, the scores for individual criteria were first estimated (either quantitatively or on the basis of expert judgement) on scales that are common across all of the options being considered, and these scores were then normalized to lie between 0 and 1 (representing the minimum and maximum of the scale). If used without further adjustment, this would make all criteria equally influential, which is appropriate only if the maximum scores for all criteria are genuinely of equal importance, which is not usually the case. A further adjustment, commonly referred to as “swing weighting”, is therefore normally applied so that the range of scores for each criterion reflects the perceived importance of the differences of performance according to each criterion so far as possible. Both the original scoring and the selection of the “swing” weights can be seriously subjective, and the outcome of such analyses is therefore normally subjected to extensive sensitivity analysis and only used as guide to the selection of the preferred option, which is ultimately justified by a narrative discussion of the balance of advantages and disadvantages among the major criteria found to be influential.

Such procedures can rapidly become complex and confusing in any non-trivial case, particular when reversed scales are involved (such that high scores represent poor performance, as is the case for example for risks and costs). The IRG is, however, content that it was applied carefully and judiciously in the Brent Decommissioning analysis. The main issues of contention are (a) whether the uncertainties in the estimated scores for some attributes are so large that the results may not provide a secure basis to inform a decision, and (b) whether the swing weightings adopted are an adequate reflection of the
relative importance of the criteria (and sub-criteria) examined. The first issue is of particular importance in deciding, for example, whether or not it would be appropriate to cut the GBS legs, discussed above in Section 4.1.3. The second issue is more general, affecting all the CA.

The standard weights used are roughly equal and were not justified except by the statement that in general DECC/BEIS regards all the main criteria as of broadly equal importance [ref 5]. However, since the scores were set on relative (normalised) scales, the numeric weights attached to them should not be similar unless the ranges of performance (between best and worst) for all criteria were all of equal absolute significance, which is highly unlikely in practice. When working with normalized scores, it is therefore essential that the swing weights should be carefully considered and justified. The IRG therefore regrets that the basis of the standard weights selected by Shell has not been documented or explained, so that it remains impossible to judge whether these are reasonable or not.

This was potentially a serious weakness of the analyses undertaken by Shell. However, in the final version of the report on the CA Procedure, a very useful analysis is included, in which the weights adopted were compared with those adopted by the CMSTG, and those that would emerge from an attempt to express all scales in monetary units. This is also a difficult and potentially contentious procedure, but the results provide some comfort in that the weights used in the CA do not bias the results in favour of options that would be detrimental to some stakeholders or the environment. On the contrary, they would appear to favour options that involve greater effort and expenditure by Shell to protect environmental and other interests than would be justified by a monetarised approach. However, some weightings when compared with the equivalent monetary weightings give a major bias to one option over others; for example the high weighting on safety risk to the workforce tends to favour leaving the GBS “legs up”, whereas the monetized weighting would cause the “legs down” option to be assessed less unfavourably.

The outcome of the MCDA is in any case based on quite subjective expert judgements about the scores for some criteria. Overall, the IRG considers that the CA procedure adopted is reasonable and that it has been applied in an appropriate manner. It has, moreover, been used as a guide rather than an over-riding determining factor in the selection of preferred options. Justification of the selection of one option over others must therefore rely heavily on the narrative explanation of the advantages and disadvantages according to the main criteria.

4.7 Decommissioning Programmes

The IRG has seen and commented on a draft of the Brent Field Decommissioning Programme [ref 1], although the recommendations of this document are not subject to formal review by the IRG. Shell responded constructively to the comments made. The IRG considers that the DP provides a satisfactory and accurate summary of the work undertaken by Shell and its contractors, but notes with regret that except in a few specific instances it makes very little reference to the (sometimes large) uncertainties in some of the estimates made. The report therefore gives a somewhat unrealistic impression of a straightforward analytical process and of greater confidence in the rationale for the conclusions than is warranted. The quantity and composition of the cell sediments is not known accurately, for example, as while it is supported by analysis of similar materials in other locations, it has been verified by just three isolated samples, all from one platform. Supporting information was obtained from surrogate samples but the uncertainty remains substantial. Similarly, the fate of any cell sediments that may be released was projected using a computer model that was not designed for the purpose, and the timing and manner of release remains highly uncertain. Simple limiting calculations (see Section 4.2.4) can provide some reassurance that this uncertainty does not fatally compromise the analysis of the options for dealing with cell sediments, but the uncertainty should be recognised. The cell contents and tri-cell cuttings are referred to as being contained, but once the GBS begin to collapse, there is no guarantee that the covering effect of the fragments will exceed the scouring effect of the turbulence they are likely to induce.
More seriously, the magnitude of the legacy risk to users of the sea after more than a few decades, if the GBS legs are left standing (Section 4.1.3) in the opinion of the IRG is unquantifiable, even within orders of magnitude, because it is not possible to reliably predict

a) The mode and rate of degradation of the concrete of the structures, especially close to the waterline.

b) The nature and frequency of future marine activities such as ship movements in the area.

c) The effectiveness of future collision avoidance procedures and practice (which currently prevent the vast majority of potential collisions).

This means that a trade-off between this potentially significant long-term risk and any other relevant factor (such as cost and risk to operators of cutting the legs) cannot realistically be based on the normal quantitatively guided CA process. This problem is glossed over in the DP. The proposal that the risks to shipping should be re-evaluated regularly (at roughly decadal intervals) provides a satisfactory means of dealing with some of the uncertainty by tracking the evolution of such risks and deciding when corrective action (such as removing the legs) may be needed, but does not guarantee that such action will be feasible.

The IRG notes that operational risks and costs (which tend to be highly correlated) are generally significant factors in discriminating between options, although alternative CAs that exclude costs have also been undertaken, and they are not decisive except for some pipelines. The operational risks and cost estimates are, however, all internal to Shell. The IRG recognises that the costs generated for the various options will be in line with Shell's Global Costing Process but notes that there has been no independent assessment of these. It is also noted that it is likely that any high operational risks could in practice probably be reduced (mitigated downwards) by a successful contractor, but no allowance for this has been made in the CAs, nor is it given any prominence in the DP.

5. Discussion

5.1 Outstanding concerns

The IRG notes that

i. If the GBS legs are left standing they will degrade progressively, and degradation is expected to be most rapid near the waterline. The upper parts of the legs are therefore expected to persist as a dangerous obstruction at or just below the sea surface and to collapse at some future time. While toppling them deliberately would conflict with current UK policy (established by Ministerial statement following OSPAR 98/3), collapse would effectively lead to “toppling by default” (i.e. in the absence of action to prevent it). The IRG considers that stakeholders are likely to expect the operators to take precautionary action to avoid such foreseeable and unsatisfactory outcomes, to ensure that liability for dealing with them does not ultimately fall to the State, should Shell and its co-venturers no longer exist.

ii. At present the disposal of material such as GBS leg segments by cutting and emplacement on the sea bed would also only exceptionally be permitted by the OSPAR guidelines [DECC/BEIS Guidance Notes 7.5]. However, so far as the IRG is aware, the balance of environmental and other impacts (pros & cons) of such a procedure have never been clearly established and there are a considerable number of GBS legs in the UK sector and elsewhere that are likely to require disposal in future. It would therefore be appropriate for this issue to be re-examined by both GBS operators and the regulator.

iii. In view of the long duration between the start of decommissioning Brent D and Brent B & C the IRG suggests that Shell should continue to sample the cell contents of Brent B & Brent C as and when opportunities arise to do so without excessive difficulty or cost, in order to improve sampling procedures and supplement and improve confidence in the results already obtained from Brent D.
iv. Shell proposes to cut the Brent Alpha jacket at 84.5 m LAT, leaving the footings in place on the sea bed. A situation may arise in future where it is deemed necessary to remove the footings leaving a clear sea bed. Over the next few decades the opportunity to cut the steel piles internally to release the footings should still be available. However, in the longer term corrosion of the tops of the piles and the remaining legs and additional marine growth could obstruct internal access and the structure may be weakened to the extent that lifting it could be difficult and risky. The latter problem could also apply if the steel piles were to be cut externally. This possible legacy problem has not been addressed.

5.2 Suggestions for continuing and future work

i. There are many uncertainties in the modelling of the fate of drill cuttings and cell contents especially in the long term, and the models available do not appear to have been developed significantly since the Drill Cuttings Initiative JIP ended in 2004. While the IRG does not consider that further modelling or analysis would have been likely to affect the main conclusions reached in this case, the situation remains unsatisfactory. A continuing JIP (preferably involving the Research Councils and academic institutions) to resume and maintain the development of such models, and to improve the estimates of key parameters involved, would be desirable to enable more reliable forecasting in future through further testing and calibration.

ii. There are no generally accepted practical thresholds for acceptable levels of impact on the water column, sea bed sediments and biota from releases from legacy structures, similar to those that have been adopted for drill cuttings. A joint effort by operators and regulators to develop such thresholds would facilitate the preparation of future environmental statements and could be initiated by considering (for example) whether and in what circumstances standard thresholds similar to those available for cuttings-related material on the sea bed that is contaminated above a defined level might be more widely applicable, and/or what modifications might be appropriate.

iii. Procedures for the Comparative Assessment of decommissioning options are not well established and may be controversial, with the selection of scaling and weighting factors being a subtle issue requiring very careful attention. The IRG welcomes the establishment of a joint industry initiative to consider whether some standardisation would be helpful, notes that OGUK has recently published guidelines on this [ref 14], and suggest that further industry work on this issue would be valuable.

6. Conclusions and Recommendations

1) The IRG has reviewed and commented on reports by Shell and its contractors on all relevant aspects of the DP, and is satisfied that a sufficiently wide range of options have been examined. The IRG has also assessed the rationale leading to the decisions by Shell and confirms that so far as it can judge the scientific, engineering and other evidence used, and the rationale developed, appear to be adequate to enable the decisions to be made. In particular the IRG accepts the evidence that supports the conclusions that

a) The complete removal of the Brent Alpha jacket is technically feasible, but may well not be the preferred option, because of the trade-off between low technical feasibility and high cost, versus small benefits to fishermen and a limited reduction of the small residual environmental impact expected.

b) The risks and technical difficulties associated with attempting to remove the Gravity Based Structures (GBS) completely would be much higher than are normally acceptable for major marine operations, and the benefits to fishermen and the environment of doing so in order to leave a small area of clean sea-bed would not be large.
c) Leaving the drill cuttings and cell contents in place means that about 22,000 m³ of hydrocarbons would remain after decommissioning. However, although it is uncertain, the risk of environmental impacts of these should be local and are not likely to extend beyond about 2-3 km from the platforms. There appears to be no reason to expect that the future release of cell content will cause regional or population level effects on pelagic or benthic organisms. For drill cuttings the potential environmental impacts are probably near or below the OSPAR thresholds for further remediation.

d) Attempts to mobilise and remove either the drill cuttings or the cell contents would be likely to create greatly increased volumes of contaminated waste, and the environmental impacts of the recovery, transport, treatment and disposal of these would be likely to be greater than those of leaving the material in place.

e) The evidence supporting the proposals for decommissioning the pipelines, and the related sea bed structures and for debris removal appears to be sound.

f) The disposal of drill cuttings and/or cell contents by re-injection into the formations accessible by wells from the existing platforms was originally considered to be a promising option. However, detailed studies showed that difficulties associated with the technical conditions of the available well stock together with subsurface geological problems made this option impracticable. New wells drilled from a new sub-sea installation located at some distance from the existing platforms would be required for disposal by re-injection. This would entail high costs, in order to reduce the small environmental impacts of leaving them in place. Other options that involve treatment of the cell contents in situ, sediment capping or extraction and platform or onshore treatment, have also been examined but not found to be preferable.

g) While removing the GBS legs is considered to be technically feasible, the risks to operating personnel of cutting the legs to -55 m and removing them would outweigh the risks to users of the sea in the short-term (i.e. for the next few decades), provided the legs are fitted with Navaids (etc.) as proposed. The IRG also recognises that some stakeholders including fishermen’s representatives have expressed a preference for the legs to remain visible.

2) The IRG is, however, concerned that despite strenuous efforts to evaluate it using the best available methods, the evidence available on the risks from leaving the GBS legs standing above sea level in the long term, until they naturally degrade to just below sea level and thereafter until total collapse on to the sea bed, is not reliable. The legs could be cut down to -55 m to comply with the IMO recommendations for a partially removed structure in the long term, and so mitigate the legacy risk to users of the sea, but at present this would be risky and expensive, and may therefore not be the preferred option. The IRG observes that

a) The legacy risk to fishermen and other users of the sea (especially shipping) is extremely uncertain in the longer term (decades to centuries), because it is not possible to reliably predict
i) The mode and rate of degradation of the concrete structures, especially close to the waterline.
ii) The nature and frequency of future marine activities such as ship movements in the area.
iii) The effectiveness of future collision avoidance procedures and practice (which currently prevent the great majority of potential collisions).

b) The proposal that the risks to shipping should be re-evaluated regularly (at roughly decadal intervals) provides a satisfactory means of dealing with the latter uncertainties, by tracking the evolution of such risks and deciding when corrective action may be needed. However, while various options for additional mitigation of the risk may be applicable, such a re-assessment does not guarantee that corrective action, potentially involving structures that may have become seriously unstable, will be feasible when it is needed. Moreover, it is possible that the policy and regulatory requirements (either UK, IMO or OSPAR) may change in the future (e.g. concerning toppling) and require or enable further action.

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3 The Environmental Statement [ref 12] refers to 16,000 tonnes of total hydrocarbons in the GBSs that may become exposed to the marine environment at some time (Table 0-5), in addition to about 5,600 tonnes of hydrocarbons estimated to be contained in the sea bed and cell top drill cuttings that are currently exposed
c) These concerns are likely to apply to all similar GBS, and the IRG considers that it is likely to become necessary to cut, remove and dispose of all GBS legs eventually, and therefore suggests that Shell and other GBS operators should plan for the execution of this work in the foreseeable future, before the legs become significantly structurally degraded, and collaborate to develop the technology for doing so, including carrying out underwater cutting trials when appropriate, possibly by means of a suitable Joint Industry Programme.

3) Assembling the necessary evidence on some aspects of the programme has proven to be difficult, despite the very extensive efforts made by and on behalf of Shell.
   a) In particular, the evidence supporting leaving the cell contents in place may be considered adequate to support the EIA, but is still uncertain because,
      i) The information available to verify the nature, quantity and composition of the cell contents is limited to that obtained from the Brent Delta cell sampling (3 cells), Brent Delta attic oil recovery (water samples from 3 additional cells), and an additional sonar sounding on Brent Bravo.
      ii) There is great uncertainty about the timing, mode and rate of eventual release of the cell contents to the environment.
      iii) So far as the IRG is aware the modelling tools available at present were not designed to evaluate the fate and environmental consequences of cell contents release.
   b) While the IRG does not consider that further observations, modelling or analysis would have been likely to affect the main conclusions reached in this case, the situation remains unsatisfactory. In order to reduce the uncertainties and also facilitate similar work in the future, the IRG suggests that Shell and other GBS operators should support continuing sampling and observations of GBS contents, and the development of better models to improve the reliability of the evaluation of the fate of cell contents and other potentially polluting materials present within such structures.

4) If the legs have been cut, it may or may not be possible to re-use or recycle them economically. The costs and risks of bringing them to shore and disposing of them there are expected to be significant, and the environmental impact of placing them on the sea bed adjacent to the platforms is likely to be small. If the legs are left to degrade they will either decay progressively or eventually topple to the sea bed by default (i.e. in the absence of action to prevent it). The IRG therefore suggests that Shell and other GBS operators should request BEIS to consider whether the current UK policy preventing deliberate “toppling” might usefully be updated to permit controlled emplacement of inert major components of decommissioned GBS platforms adjacent to them.

5) Shell has proposed a well-considered survey programme to assess any environmental changes to the sea bed adjacent to and remote from the platforms, once decommissioning of the Field is complete. However, a programme for longer-term monitoring of the structures remaining in place has not yet been proposed, but is to be agreed between Shell and BEIS once the Decommissioning Programme is accepted. The IRG considers that some stakeholders would welcome initial proposals being included in the DP.

6) The IRG notes that the research being undertaken by the collaborative industry-funded INSITE\(^4\) programme should in future also enable better assessments of the balance of benefits and adverse ecological impacts of leaving GBSs in place. The IRG commends Shell’s support for this programme, and suggests that it should be continued.

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\(^4\) Declaration of Interest: Two IRG members are also members of the INSITE Scientific Advisory Board.
7. References

1) Shell, 2017, Brent Field Decommissioning Programmes, BDE-F-GEN-AA-5880-00015
2) Decommissioning of Large Offshore Structures – The Role of an Independent Review Group (IRG); Ocean Engineering 113 (2016 pp11-17)
4) 1992 Convention for the Protection of the Marine Environment of the North East Atlantic (the OSPAR Convention) http://www.ospar.org/convention
12) DNV GL, 2017, Brent Field Decommissioning Environmental Statement, BDE-F-GEN-HE-0702-00006
13) Shell, 2016, An Assessment of the weightings used to perform Comparative Assessments, BDE-F-GEN-HX-0580-00002 R01
19) Shell, 2017, Brent Decommissioning Stakeholder Engagement Report, BDE-F-GEN-HX-5480-00001
20) Shell, 2017, Brent Field Decommissioning Comparative assessment Procedure, BDE-F-GEN-QA-6003-00007
21) BMT Cordah: GBS Cell Water & Sediment Modelling - Overarching Report, BDE-F-GBS-0709-00012
Glossary

AP  Alkyl Phenols
ASR  Alkali Silicate Reaction
BEIS  Department for Business, Energy & Industrial Strategy
BTEX  Sum of the monoaromatic compounds benzene, toluene, ethylbenzene, and xylenes
CMSTG  Cell Contents Management Stakeholder Task Group
CA  Comparative Assessment
CCS  Carbon Capture & Storage
CO  Commissioning Organisation
CoP  Cessation of Production
CO₂  Carbon Dioxide
DECC  Department of Energy and Climate Change (became part of Department for Business, Energy & Industrial Strategy in July 2016)
DP  Decommissioning Programmes (for the Brent Field)
EIA  Environmental Impact Assessment
ES  Environmental Statement
FishSafe  Scheme to promote fishermen's awareness of offshore surface and sub-sea structures within the UK Continental Shelf
GBS  Gravity Based Structure(s)
H₂S  Hydrogen Sulphide
IMO  International Maritime Organisation
INSITE  INSITE Programme - Influence of man-made structures in the ecosystem
IRG  Independent Review Group
JIP  Joint Industry Project
LoD  Limit of Detection
MCDA  Multi-Criterion Decision Analysis
MNA  Monitored Natural Attenuation
Navaids  Navigational Aids
NORM  Naturally Occurring Radioactive Materials
OBM  Oil-based Mud
OGUK  Oil & Gas UK
OPF  Organic Phase Fluids
OSPAR  OSPAR Convention - Convention for the Protection of the Marine Environment of the North-East Atlantic - Oslo and Paris Commissions 1992
PAH  Polycyclic Aromatic Hydrocarbons
PCB  PolyChlorinated Biphenyls
PEC  Predicted Environmental Concentration
PLL  Potential Loss of Life
PNEC  Predicted No Effects Concentration
PROTEUS  BMT Cordah computer model for the prediction of the behaviour, fate, transport and impact of discharged contaminants
ROV  Remotely Operated Vehicle
SBM  Synthetic-based Mud
SLV  Single Lift Vessel
SRG  Scientific Review Group
TCC  Thermal Cuttings Cleaning
TD  Technical Documents (supporting the Decommissioning Programmes for the Brent Field)
THC  Total HydroCarbons
UK  United Kingdom
UKOOA  United Kingdom Offshore Operators Association
UKHO  United Kingdom Hydrographic Office
WBM  Water-based Mud
Annex 1 - Terms of Reference

Independent Review Group (IRG) Terms of Reference, Draft 2, 9th January 2007… to establish an Independent Review Group (IRG) under the chairmanship of Professor J.G. Shepherd which will:

- Be constituted in January 2007 and remain in operation until the submission of the Brent Decommissioning Programme (or December 2008, whichever comes first),
- Address comparative study issues relating to decommissioning options for the Gravity Based Structures including cell remediation measures and jacket footings, drill cuttings and pipelines;
- Read and review existing project documentation to ensure an understanding of the relevant issues for the comparative assessment process;
- Read and review all relevant comparative assessment study work (including contractor scopes of work) commissioned for or produced by Shell U.K. Limited (Shell);
- Provide views/guidance on the above in respect of the scope, clarity, completeness, methodology, relevance and objectivity of conclusions;
- Advise on any further research or actions to address identified gaps that would otherwise prevent an informed decision;
- Make recommendations for additional work as necessary which should be practicable and achievable within the timeframe for the decommissioning programme submission;
- If requested, confirm that all relevant stakeholder comments have been addressed within the scope of each study where practicable to do so;
- Provide written reports with commentary on each study for use on Shell's public website;
- Provide a statement for public use by Shell at the conclusion of the comparative assessment process on the group's findings for individual studies and on the process which Shell will employ to draw together a holistic view of the comparative assessment work;
- Normally provide any input within 10 working days of a request from Shell;
- The IRG, or any member thereof, will have the right to publish the findings of their scientific review including any objection after notifying Shell with sufficient notice to enable Shell to comment and correct any misunderstandings;
- The IRG will operate under the chairmanship of Professor J.G. Shepherd and will comprise six members plus a secretary, calling in additional expertise if necessary;
- Frequency of group meetings will depend on the comparative assessment study schedule but allowance for six meetings of two days each will be made;
- At least one group member will attend each stakeholder consultation general meeting as an independent observer / expert, when possible/appropriate; and
- Shell will provide a main point of contact and liaison.
Annex 2 - IRG Members’ details

Professor John G. Shepherd
CBE, FRS, CMath, FIMA, MA, PhD

Professor John Shepherd is Emeritus Professor of Earth System Science in the School of Ocean & Earth Science at the National Oceanography Centre, University of Southampton. He is a physicist by training, but has worked on a wide range of environmental issues, including the transport of sulphur dioxide in the atmospheric boundary layer, the dispersion of tracers in the deep ocean, the assessment & control of radioactive waste disposal in the sea, the assessment and management of marine fish stocks, and most recently on Earth System Modelling.

His current research interests are in climate change and the natural variability of the climate system on long time-scales, and in the development and application of intermediate complexity models of the Earth climate system, especially for the interpretation of the palaeo-climate record.

From 1989-1994 he was Deputy Director of the MAFF Fisheries Laboratory at Lowestoft, and the principal scientific adviser to the UK government on marine fisheries management. He has been at the University of Southampton since 1994, and from 1994-1999 he was the first Director of what is now the National Oceanography Centre, Southampton.

He has extensive experience of international scientific assessments and advice in controversial areas such as fisheries management and radioactive waste disposal, as well as climate change, and has taken a particular interest in the interaction between science, economics, and public policy.

He was a Deputy Director of the Tyndall Centre for Climate Change Research from 2001 to 2010, and is a former member of the DEFRA Science Advisory Council. He has chaired independent reviews of several offshore decommissioning projects including the UKOOA Drill Cuttings Initiative and the BP Northwest Hutton decommissioning, and was Chair of the Scientific Advisory Group of the UK Department of Energy & Climate Change [dates].

He is a Fellow of the Institute of Mathematics and its Applications, was elected a Fellow of the Royal Society in 1999, was a member of the Royal Society’s study on Ocean Acidification (2005) and chaired its study on Geoengineering the Climate (2009).

Associate Professor Torgeir Bakke
BScChem/Biol, Cand.real. (MSc equiv.)

Associate Professor Bakke received his Cand.real. degree in marine biology (zoology) at the University of Bergen, Norway in 1972. From 1972 to 1978 he held a position as Assistant Professor at the University of Bergen. During 1978 – 1980 he was Research Scientist at the Institute of Marine Research in Bergen. Since 1980 and until he retired in 2015, he was research scientist at the Norwegian Institute for Water Research, NIVA, until he retired in 2015. In NIVA he has also held positions as Head of the Marine Department (1991-1995), Research Manager for Industry and for Oil and Gas (1985 – 1998), and Senior Research Scientist and Coordinator for Oil&Gas Activities (1998 – 2015).

During 2008 – 2011 he held a part time position as Associate Professor in marine biology at the University of Oslo. At present he is independent senior consultant in marine environmental issues. His main field of research is fate and effects of oil hydrocarbons on marine organisms and systems, primarily centred on long term experiments in large scale experimental ecosystems (mesocosms), where his speciality has been research on the physiological responses of invertebrates to hydrocarbons and other stressors. Since 1982 he has conducted research on the environmental impact of drill cuttings, and has been responsible for the development of simulated sea bed mesocosm tests on the degradation and effects of drill cuttings. He also has considerable experience...
in long term chemical and biological monitoring in rocky shore and soft sediment ecosystems, environmental impact and risk assessments of industrial activities, and offshore environmental management. Since 1987 he has been coordinator for the Norwegian Expert Group on the Evaluation of Environmental Monitoring around Offshore Fields, and he has been in charge of developing national guidelines for characterization of drill cuttings piles and for offshore environmental monitoring.

**Professor Günther F. Claus**

BSc, MSc, PhD, FRINA, MSNAME

Professor Claus studied technical physics at the Technical Universities at Munich (B.Sc. – 1964) and Berlin (M.Sc.), and completed his doctorate at the Institute of Aerospace (TU Berlin) in the year 1968. He established the new field ‘ocean engineering’ at the Technical University Berlin and became professor of Ocean Engineering in 1972. After research visits at the MIT-Department of Ocean Engineering, the Institute of NAOE, University of California at Berkeley, and the Indian Institute of Technology, Madras, he was offered the first Chair of Ocean Engineering in Germany at the TU Berlin in 1973. For many years he served as a Director of the Institute of Naval Architecture and Ocean Engineering, the Dean of the Faculty of Mechanical Engineering and Transport Systems and was a Senator at the Academic Council for 12 years.

The extensive research activities of Günther Claus - focusing on the design and hydromechanics of offshore structures as well as on deep sea technology – cover projects on capsizing of ships, design and optimisation of offshore platforms, pipelaying vessels and floating cranes as well as the development of oil skimming vessels, deepsea shuttles and ocean mining systems. For the deterministic analysis of cause-reaction chains he developed a seakeeping test procedure which uses tailored extreme waves – embedded in irregular seas – to investigate precisely wave/structure interactions.

With his research assistants, colleagues and industry partners he published more than 400 papers. Under his guidance more than 35 Ph.D. theses have been successfully completed – based on research projects of the European Union, the German Ministries BMBF (Research and Development) and BMWi (Economy and Technology), the German Science Foundation (DFG) and the Association of Industrial Partners.

Günther Claus served as chairman and member at ITTC and ISSC, is member of STG (executive board) In offshore platform decommissioning he served as a member in the IRG of Brent Spar and was engaged in the Scientific Review Group (SRG) for the Ekofisk Field.

**Professor William D. Dover**

FIMechE, CEng, FINDT

Professor Dover has been a Professor at University College London since 1983, Shell Professor of Mechanical Engineering since 1987, Centre Coordinator of the London Centre for Marine Technology, and Head of the UCL NDE Centre. He is currently the Emeritus Shell Professor of Mechanical Engineering at UCL.

Professor Dover established the UCL NDE Centre in 1985 and was a founding member of TSC Inspection Systems. He has led many major projects in Fatigue Fracture Mechanics of Offshore Structures (the Marine Technology Cohesive Fatigue Programmes and EU projects such as RISC), Inspection Reliability (the UCL Underwater NDE Centre and European Programmes ICON, EDICS, and RACH), and NDT research (ACFM development and the EU AIRES project).

Current interests are Chairman of the UCL NDE Centre, Structural Integrity Monitoring (SIMoNET www.simonet.org) and research into non-contacting stress measurement (including residual stress), the ACSM StressProbe approach.
He has been a member of various Government committees, acted as a Consultant for the World Bank and been Programme Champion for a series of EPSRC National Programmes on Fatigue of Offshore Structures. Professor Dover has been author, co-author, and editor of some 250 papers and books.

**Professor Jürgen Rulköter**
Dipl.-Chem., Dr. rer. nat. habil.

Professor Rulköter is a professor of organic geochemistry at the University of Oldenburg, Germany. He received his PhD degree at the University of Cologne in 1974. With his experience in analytical and natural product chemistry he joined the Institute of Petroleum and Organic Geochemistry at the Research Centre Jülich (Germany) where he stayed for 17 years to investigate the bulk and molecular composition of fossil organic matter and petroleum. This research largely contributed to the understanding of the chemical processes and quantitative aspects of petroleum formation.

Biological marker parameters developed during that time are now widely used in the petroleum industry for oil/oil and oil/source rock correlation, for maturity assessment of organic matter and crude oils and for studying bacterial degradation of oils in reservoirs and in the environment.

With the development of environmental concerns, Professor Rulköter extended his research to the microbial transformation of petroleum compounds in natural oil seeps and anthropogenic oil spills and, as a side aspect, to the investigation of asphalts used by the ancient Egyptians for mummification.

After he joined the University of Oldenburg in 1992, much of his research was devoted to palaeoenvironmental and palaeoclimatic reconstructions based on the organic matter in marine sediments from the continental margins of the world’s oceans and to early diagenetic processes in coastal sediments of Holocene and Recent age.

He continued to work, however, on several aspects of petroleum in the environment and, among others, served on the NERC Committee on Decommissioning dealing with the scientific aspects of deep sea disposal of offshore structures, with the Brent Spar as an example of the environmental aspects of dismantling and using its parts for a harbour extension. In 2010, he became a member of the Research Board of the Gulf of Mexico Research Initiative.

**Professor W. Brian Wilkinson**
BScEng, BScGeol, PhD, DSc, FICE, FCIWEM, FGS, CEng, CGeol, F Russ Acad. Nat.Sci.

Professor Wilkinson is an environmental engineer, geologist and surface and ground water hydrologist with 50 years experience. In 1989 he was appointed Director of the Institute of Hydrology and in 1995 became the first Director of the Centre for Ecology and Hydrology with responsibility for 800 staff. From 1984 to 1989 he was Professor of Civil Engineering at Cranfield University. He has been Visiting Professor at the Universities of Reading and Newcastle upon Tyne. His PhD from University of Manchester (1968) was in geotechnics and his DSc from the University of Durham focussed on the permeability and storage properties of soil and rocks. As Head of the Water Resources Division of the UK Water Research Centre from 1974 to 1984 he led a wide range of research projects. He has worked with consulting engineers on the design and construction of large dams and water supply projects and was a Senior Engineer at the Water Resources Board (1969 – 1974).

He has been the UK Government Hydrological Adviser to the World Meteorological Organisation Commission for Hydrology and the UK Science Representative and Leader of the UK Science Delegation to the 1997 UNESCO General Conference. He was a founder member of the European Water Research Directors’ group EURAQUA.
Recently he has been involved in assessment and monitoring of the EC environmental research programme and has led a UNESCO International Review Panel examining the environmental impacts of proposed uranium mining in a major World Heritage site in Australia. He has been an independent consultant on many major engineering and environmental assessment projects, an expert witness on a number of occasions and until recently was Advisor to the Transport for London Safety, Health and Environment Committee.

He has published some 90 papers and edited several books.

Mr Richard J. Clements  
BSc, CEng, MIMechE, MIMarEST

Mr Clements studied mechanical engineering at the Lanchester College of Technology (now the University of Coventry). The early part of his career was spent in the marine application of gas turbines with Rolls Royce before moving to Shell International Marine as a project engineer. The work involved finding solutions to problems arising from the operation of tankers, including the development of efficient methods of operating steam turbine propulsion plant below the design condition to minimise fuel costs; investigating the possibility of using nuclear power for marine propulsion plants as an alternative to oil fuel; finding means of access for inspecting the large cargo tanks and improving the braking performance of anchor windlasses to avoid losing anchors. Mr Clements was later seconded to Shell Research to develop sub sea valves and actuators for the offshore industry before returning to Shell International Marine to work on problems with the handling of residual fuel oils on board ship. He has also spent has six years managing projects for a UK RTD funding agency, many of them associated with the offshore petroleum industry. Mr Clements has been the Secretary for a number of similar review groups concerned with the disposal of drill cuttings and other offshore decommissioning projects.

Professor David R. Davies  
Bsc., PhD.

Professor Davies has a first degree in Chemistry from Exeter University and a PhD in Theoretical and Experimental Chemical Physics from the same University. His initial industrial experience was 4 years with Shell Chemical UK Ltd. In Stanlow, Cheshire where he was involved in the solution of process control and chemical engineering problems on their plants making a wide variety of products.  
He subsequently spent the next 22 years with Shell Exploration & Production, Rijswijk, The Netherlands working on Technology Development & Application. He led theoretical and experimental groups working in virtually all areas of Drilling and Production Operations e.g. Well Stimulation, hydraulic Fracturing, Rock Mechanics, Fluid Mechanics, Well Performance modelling, Drilling Fluids, Well Cementing, etc. He was assigned for 3 years to Brunei Shell Petroleum Ltd. as a Senior Engineer working in Drilling and Production Operations overseeing well construction by 13 drilling rigs as well as operations of a workover / stimulation vessel and production hoists.

He joined Heriot-Watt University in 1996 and now holds the position of Professor in Production Technology. He presents Production Technology to his students in its broadest sense to cover the traditional Production Engineering subjects as well as emphasising the importance of subsurface reservoir and the surface facilities on the actual well performance. The impact of environmental aspects and mitigation measures on production activities is of particular interest.
Working with colleagues and students, his current research efforts include production oriented projects in the areas of Horizontal / Smart Well Inflow / Well Testing and its relationship to Reservoir Description, Sand Control, Artificial Lift (Gas Lift & ESPs), Water Control, Formation Impairment, Water Injection etc. He leads an industrially supported project now in its 11th year entitled “Added Value of Intelligent Wells and Fields system Technology”. It studies the application of "Intelligent wells" allow "the installation, operation, monitoring and control of completions without the need for conventional interventions so as to increase the "value" of hydrocarbon reserves. Modelling of intelligent wells and the development of methodologies to quantify their value aids in the design and specification of remote control and monitoring systems as well as improving reservoir management pro cesses and project profitability.

He is an active member of the Society of Petroleum Engineers, having sat on many conference and forum committees as well as journal editorial boards. During 1995/6 he was a Distinguished Lecturer on the topic of "Well Productivity Optimisation".

Professor Davies has authored more than 100 open literature publications and holds 8 patents and 10 research disclosures.

**Professor Quentin Fisher**
BSc, PhD

Quentin Fisher is Professor of Petroleum Geoengineering at the University of Leeds. He was awarded a PhD in low temperature geochemistry from the University of Leeds in 1993. He was worked for 18 years as a consultant conducting fault seal analysis for the petroleum industry. In 2007, he moved to the University of Leeds where is established the Wolfson Multiphase Flow laboratory. His research focuses on integrating the various upstream petroleum geoscience and engineering disciplines (e.g. petroleum geology, petrophysics, geophysics, geomechanics and petroleum engineering). In recent years, he’s concentrated on unconventional reservoirs and coupled fluid flow-geomechanical modelling. He has been involved in several large joint industry projects including IPEGG (Integrated Petroleum Engineering, Geomechanics and Geophysics); PETGAS (petrophysics of tight gas sandstones), SHAPE (shale permeability analysis); FRACGAS (hydraulic fracturing of shales), and GESE (geomechanics of tight gas sandstone reservoirs).

**Professor Ian Main**
BSc, MSc, PhD, FRSE.

Ian Main is currently Professor of Seismology and Rock Physics at the University of Edinburgh. He is interested in the processes that lead up to catastrophic failure events, from earthquakes, rock fracture, and volcanic eruptions to failure of building materials and bridges. He is particularly interested in the population dynamics of localised brittle failure as a complex, non-linear (unreasonable) system, as well as the influence of old, new and reactivated faults and fault zones on fluid flow underground, including oil and gas fields, groundwater aquifers, and potential CO2 storage sites. Current research projects involve: observing and modelling brittle rock deformation in the laboratory and in a deep-sea experiment; geo-hazard forecasting in real time using a web-based portal; Strategies and tools for Real-Time EArthquake Risk Reduction (REAKT), earthquake statistics, especially triggering phenomena; modelling and observing localising signatures of catastrophic failure in rocks and other complex materials; the effect of stress, faults and fractures on flow rates in oil reservoirs; and identifying reservoir fluid compartments.

In knowledge transfer he is working on commercialisation of a recently-developed method of statistical reservoir analysis, as an aid to enhanced oil recovery and monitoring of CO2 storage sites. Ian is currently a member of: The HEFCE Research Excellence Framework (REF) Panel on Earth
Systems and Environmental Sciences; the Research Advisory Forum of the Scottish Energy Technology Partnership; and the Scottish Regional Advisory Group for Enhanced Learning and Research for Humanitarian Assistance. He gave the Bullerwell lecture in Geophysics in 1997, and moderated the Nature debate on earthquake prediction in 1999. He was elected a fellow of the Royal Society of Edinburgh in 2009, and has just completed a Scottish Government/RSE research support fellowship.
Annex 3 – List of IRG Meetings & other activities

An inaugural meeting was held on 30th-31st January 2007 to acquaint the IRG with the scope of the Brent Decommissioning Project and to establish working procedures for a project that was expected to last for two years. This was followed by a second meeting on 14-15th May 2007 that included an Initial discussion of reports on the subjects of environmental management, complete removal option, pipelines and CO2 Re-use. The IRG suggested high priority issues considered necessary to provide the necessary foundation for decisions to be taken, among these being the means of access for sampling. The third meeting then took place on 11-12th December 2007 when the IRG was concerned that reports for review were arriving rather slowly and Shell reported that there had been a slippage of 4-5 months. The feasibility phase had been completed and a decision taken to concentrate on the decommissioning of Brent Delta. The IRG had reviewed reports on Gravity Based Structures (GBSs), their removal and environmental studies and these were discussed prior to Shell introducing a Select Phase Methodology Report.

The fourth meeting took place on 30th September-1st October 2008 when the IRG was concerned that Shell’s responses to various IRG reviews had been received only just before the meeting. Shell reported on the change of personnel responsible for the project, the expansion of the decommissioning team and the development of a new generation of studies. Shell informed the IRG about the study structure and the concept selection process; it was expected that the Brent Delta Decommissioning Programme would be close to finalisation in 2010. The subjects discussed at this meeting included GBSs, the cell contents, sampling, environmental studies and a feasibility report and Select Phase methodology. The fifth meeting on 17-18th September 2009 Refloat continued the discussion of feasibility studies, offshore and onshore deconstruct studies, long term fate modelling and sampling. The sixth meeting took place on 2nd – 3rd February 2010 when the IRG expressed a concern that it was not interfacing with Shell as well as it should; it had not received any response to its questions about refloating and had been presented with some 40 reports to examine over a very short time and these appeared to be final reports already approved by Shell. Discussion of refloat continued with new subject of long term modelling and remediation work introduced. Reports on risk, energy and environment matters and leg cutting had been expected for review but not received. The seventh meeting on 11-12th May 2010 was concerned with GBS refloat, long term fate modelling and derogation while Shell introduced a series of 7 Decision Papers. The eighth meeting took place on 15th - 16th November 2010 and continued the discussion of GBS Refloat, long term fate modelling and remediation while Shell introduced a Consolidated Concept Select Report.

The ninth and tenth meetings took place on 28th - 29th June 2011 and 19th-21st March 2012 respectively. The GBS refloat studies had shown that the risks involved were unlikely to be acceptable so the discussion moved on to GBS derogation, degradation and long term monitoring. The other main subject was environmental matters associated with drill cuttings and cell remediation leading to long term fate modelling. The eleventh meeting on 30th-31st May 2012 continued these discussions and extended to consider pipelines. Similarly, the twelfth and thirteenth meetings on 23rd - 25th July 2012 and 23rd - 24th October 2012 continued the discussion of the consequences of GBS derogation and extended to consider the feasibility of removal of the GBS legs. The subjects of environment impact, cell sampling and remediation and long term fate modelling continued to be discussed. As Shell developed more information on these subjects, they continued to be part of all the meetings up to the time when the Decommissioning Programme was submitted to the government department (BEIS) for consideration. The possibility of sub-sea re-injection of the cell contents was considered by Shell and relevant reports were discussed at the fourteenth 14th meeting and fifteenth meetings on 4-6th March 2013 and 3rd - 5th June 2013 in addition to the previous topics discussed.

The sixteenth and seventeenth meetings held on 13th - 15th January 2014 and 20th - 22nd May 2014 continued the discussions of the consequences of GBS derogation and the feasibility of removal of the GBS legs as Shell developed greater understanding of the technology available and its limitations.
Comparative assessment methodology was a new topic of discussion as means of making reasonable informed choices between some very disparate options. Cell remediation sampling and analysis became more a more significant topic for discussion as Shell obtained more relevant information from various sources and the opportunities to take samples became more frequent. These discussions continued through the eighteenth and nineteenth meetings on 20th-22nd October 2014 and 4th-5th February 2015, which also saw the completion of the discussions of re-injection. At this time, Shell introduced the documentation in the form of Technical Documents that would accompany the Decommissioning Programme to be submitted for government approval.

A significant feature of the twentieth meeting held on 13th - 15th April 2015 was a review of the Brent Project overall from the IRG perspective considering the platforms, contaminants and modelling, pipelines, environmental impacts and statement, long term issues (monitoring, maintenance and liability, the Comparative Assessment process and the Decommissioning Programme. This was continued at the twenty-first meeting held on 23rd - 25th September 2015 although the IRG was then waiting for reports on the Environmental Impacts and Statement, Long term issues (monitoring, maintenance and liability, the Comparative Assessment process and the Decommissioning Programme.

The twenty-second, twenty-third and twenty-fourth meetings held on 21st - 23rd March 2016, 31st May – 2nd June 2016 and 20th – 22nd July 2016 were mainly concerned with progress with the production of outstanding reports and the progress with current reviews of reports, many of which were later revisions of earlier reports at this time. The subjects that the IRG concentrated on at the twenty-sixth meeting held on 26th – 28th September 2016 were weightings and Comparative Assessments, the periodic reassessment of safety risks and the Brent Field Decommissioning Programme and Technical Documents. Preliminary discussions on the content of the IRG Final Report were also held.

The twenty-seventh meeting held on 29th - 30th November 2016 was a private meeting for the IRG to discuss outstanding points for its Final Report.

A number of teleconferences with Shell were held when insufficient progress had been made with documentation to justify a meeting and whenever the need arose, the IRG was represented at other meetings associated with the Brent Field decommissioning in order to understand the main concerns of Stakeholders and to be able to represent these in discussions with Shell and in IRG review comments on Shell reports. These were the series of Stakeholder Meetings arranged by Shell and reported in Section 3.3 and the Cell Contents Management Stakeholder Task Group, the GBS Peer Review Workshop, the Environmental Scoring Plenary Workshop and the Technical Feasibility [Scoring Plenary] Workshop reported in Section 3.4.