Brent Decommissioning Derogation: An evaluation

on behalf of

The Ministry of Infrastructure and Water Management
Government of The Netherlands

by

an independent evaluation group

4 October 2019

Contents

Preface

The Brent installations in the northern North Sea, used for oil and gas extraction since the 1970s, are being decommissioned. Shell U.K. Limited (hereafter Shell) proposes a derogation from the OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations that states that *"The dumping, and the leaving wholly or partly in place, of disused offshore installations within the maritime area is prohibited"*. For this purpose, Shell submitted a Brent Decommissioning Derogation Assessment report to the UK government in November 2018.

The topsides of all four installations (Brent Alpha, Bravo, Charlie and Delta) and the upper half of the Brent Alpha steel jacket will be removed by Shell, as well as as much as possible of the "attic oil" and "interface material" left in the storage cells of the Brent Bravo, Charlie and Delta Gravity Based Structures (GBSs). The derogation assessment explores various options for the decommissioning of the remaining Brent field materials, excluding pipelines on the sea bed, and the drill cuttings piles (~60,000 m^3) accumulated on the sea bed, on top of the GBS cells, and in the GBS tri-cells. The assessment recommends leaving in place:

- the Brent Alpha footings, i.e. the lower half of the steel jacket (~21,000 tonnes),
- the Brent Bravo (~345,000 tonnes), Charlie (~297,000 tonnes) and Delta (~331,000 tonnes) GBSs including legs penetrating the sea surface,
- the contaminated sediments (~40,000 m^3) and potentially contaminated ballast sands, and oily water (~640,000 m^3) in the GBS storage cells,
- and the contaminated material in the Brent Bravo and Delta legs (~4,000 m^3) and minicells (~500 m^3).

The Brent Decommissioning Derogation Assessment lists various risks involved in leaving in place the above (and alternatively removing) the materials. The considered risks range from relatively short-lived (days/weeks/months) in terms of the future environmental impact of the exposed GBS cell contents, to long-term risks in terms of dangers to the users of the sea until the structures have degraded to a level that they no longer impact shipping and fishing.

The Ministry of Infrastructure and Water Management of the Dutch government decided on an independent review of the derogation assessment in order to formulate a response to the proposed derogation. In August 2019 an independent evaluation group consisting of four scientists was established. The group was requested to review and evaluate the Shell report, as well as an earlier review by an Independent Review Group (IRG) (February 2017), the review by Scientia et Sagacitas Ltd. (2019) and the correspondence between the United Kingdom and Germany regarding the Brent Decommissioning Derogation. The Ministry of Infrastructure and Water Management requested an evaluation formulated as answers to the seven specific research questions listed in the next section.

Research questions

1. Is the assessment method used by Shell in accordance with OSPAR Decision 98/3 Annex 2?

2. Has Shell made sufficient effort to determine the composition of the contents of the Gravity Base Structure cells?

3. Is it technically feasible to remove the contents from the GBS cells and process them on land? If so, what are the environmental and safety implications? To what extent is it possible to limit or mitigate these effects?

4. Is it environmentally and safety-wise better to leave the contents in the GBS cells?

5. Has Shell considered the Best Available Technology as the basis for its investigations?

6. Are the uncertainties mentioned in the investigation reports justified?

7. What are your recommendations or advice with respect to the Brent decommissioning derogation plan?

Evaluation

Question 1: Accordance with OSPAR Decision 98/3 Annex 2

The Brent Decommissioning Derogation Assessment (Shell, 2018) is likely insufficient to enable the competent authority of the relevant contracting party to draw reasoned conclusions on whether or not to issue a permit under paragraph 3 of OSPAR Decision 98/3.

Stipulations in OSPAR Decision 98/3 Annex 2 that **have or have likely been met**:

- Safety considerations associated with removal and disposal (see Question 3).
- Sufficiently comprehensive assessment of of the decommissioning timeline.
- Taking into account the environmental impact of disposal and recycling options on land including emissions to the atmosphere, leaching to groundwater, discharges to surface fresh water (see Question 3).
- Taking into account the consumption of natural resources and energy associated with reuse or recycling of the studied options.
- Taking into account the economic aspects of the studied options.

Stipulations in OSPAR Decision 98/3 Annex 2 that **have not or have likely not been met**:

- Recognising the OSPAR-preferred option (reuse, recycle or disposal on land) (see Question 7).
- Sufficiently comprehensive assessment of all available options (see Questions 2&5).
- Sufficiently comprehensive assessment of the substances contained within the cells (see Question 2).
- Sufficiently comprehensive assessment of the cell content removal processes considered (see Question 3).
- Sufficiently comprehensive assessment of the extent to which cell content may escape (see Question 6).
- Sufficiently comprehensive assessment of the potential impacts of all options including the fate of the cell contents, drill cuttings and installations, and their future impact on the marine environment (see Question 6).
- Sufficiently comprehensive information to enable a reasoned judgement on the practicability of each of the disposal options, and to allow for an authoritative comparative evaluation (see Questions 2&6).
- Sufficiently comprehensive information on all technical and engineering aspects of the options, including reuse and recycling, and the impacts associated with cleaning, or removing chemicals from, the installation while offshore (see Questions 2&6).
- Taking into account the other consequences to the physical environment which may be expected to result from the options (see Question 6).
- Taking into account the inherent uncertainties associated with each option, and basing them upon conservative assumptions about potential impacts (see Question 6).

- Taking into account the cumulative effects from the disposal of installations in the maritime area and existing stresses on the marine environment arising from other human activities (see Questions 6&7).
- Sufficiently comprehensive information on the current physical, chemical and biological nature of the sea bed and water column (see Question 6).
- Considering what management measures might be required to prevent or mitigate adverse consequences of the disposal at sea (see Questions 6&7).

Question 2: Efforts made to determine GBS cell contents

The characterization of the concrete GBS storage cell contents is the basis for environmental analyses and the Comparative Assessment (CA) of the remediation and removal options in the Brent Decommissioning Derogation Assessment, and therefore of paramount importance. Sampling has been carried out on three Brent Delta storage cells out of a total of 42 cells used for oil storage in all three GBSs. The cell contents of Brent Charlie and Bravo are estimated using extrapolation of the Delta data (page 166), which Shell justified by stating that the oil comes from the same reservoir. The sampling has only been carried out in the upper layers of the sediment for practical reasons,. Extrapolation to lower sediment levels is uncertain, as 1) the content of heavy petroleum trace constituents (C15+) can vary during the production lifetime of a reservoir, 2) the segregation of heavy oil components in the sediment layer may differ depending on the exact conditions in each storage cell, and 3) the use of production chemicals changes over time.

The cells contain five main classes of materials: attic oil, “interphase material”, oily water, sediment and sand ballast (page 164). Attic oil and interphase material is planned for removal so the focus of Shell’s efforts was on sampling and analysis of the oily sediment and water content of the GBSs. The sampling campaign provided 9.6 L of water and 6 kg of sediment (page 166), which is a very limited sample volume given the reported cell content values (40,000 m^3 of solid material and 640,000 m^3 of contaminated water) (page 165). The cell content volumes are estimated from 3D sonar measurements carried out in the three cells on Brent Delta, before again extrapolating to the other cells and platforms (page 167). Sampling of GBS leg contents involved eight samples taken on Brent Delta, and sampling was also carried out in minicells on Brent Delta and Bravo. The leg and minicell contents are reported to be 1-2 orders of magnitude smaller than those of the GBS cells (page 49).

The chemical analysis of the sediment and water samples has focused on heavy metals, total petroleum hydrocarbon and sub-classes primarily PAH, BTEX, phenols, PCB and some cyclic compounds. Tributyltin, octylphenol and nonylphenol which probably originate mainly from production chemicals were measured (page 168, 170, Shell 2017 page 60). There has been no notable effort to characterize the hydrocarbons in detail beyond this with particular respect to environmentally persistent compounds, while some measurements of naturally occurring radioactive material (NORM) have been carried out for the cell water and sediment in Brent Delta (Shell 2017, page 39). There is large uncertainty in the assumption that the cell contents can be estimated using extrapolation, as seen by the variation in individual compound classes in the three samples.

The sampling of the cell content was limited to the upper layers of the sediment, which may not justify the extrapolation over the three sampled cells, and do not justify the extrapolation over 42 cells. It can be concluded that although Shell made considerable efforts to determine the composition of the contents of three of the Gravity Base Structure cells, their efforts cannot be deemed sufficient to determine the potential risk of leaving the sediment and cell water in place in the 42 cells.

Question 3: Technical feasibility and environmental/safety implications of cell content removal

The Brent Decommissioning Derogation Assessment states that it is technically feasible to remove the GBS cell contents and ship them to shore. The suggested removal methods (page 172) require the drilling of large access holes in the cell tops that could entail safety risks to the personnel (and that may be mitigated with technological developments). Safer removal methods can be employed by taking advantage of the existing pipework system in Brent Bravo and Charlie. An engineering study of the existing GBS pipework concludes that *"the existing pipework could be used to pump fluids to and from the storage cells"* after modifications such as pump redesign, but is *"not suitable for the deployment of equipment capable of recovering or agitating the storage cell sediment"*, and that the use of the pipework *"would require the topside to be in place"* and the drawdown to be maintained (pages 173-174).

Alternative 1: Extraction of the hydrocarbon contents using an injected fluid
This method does not extract the cell sediments, but only the organic contents, which contain the main pollutants and toxic compounds. Shell has large inhouse expertise and years of experience in recovering immobile hydrocarbon phases from sand, which is unmentioned in their derogation assessments. The injected fluid can be either a hydrocarbon solvent (requires pumps that can inject hydrocarbons), a surfactant solution, or a solvent that is mutually soluble in water and oil. For the latter option, for example, Shell has recently shown that dimethyl ether is very effective in dissolving in oil and mobilizing it, while it is easily separated later in a flash drum[1]. This method requires circulation of fluids in the cells - their subsequent extraction removes the hydrocarbon phase from the residue. Although this option requires further investigation, the safety risks are expected to be lower than those associated with underwater operations, since it essentially makes use of equipment already in place on the platform. Injection of flammable solvents such as dimethyl ether or light hydrocarbons increases the risk of fire in case of leakage and requires further safety investigation of the pipeworks' integrity. Since the pipework is inside the utility legs, the environmental risk of release of the mixture of solvent and separated contaminants to the seawater is not substantial, but needs to be

[1] Chernetsky, A., et al., 2015, November. A novel enhanced oil recovery technique: experimental results and modelling workflow of the DME enhanced waterflood technology. In *Abu Dhabi International Petroleum Exhibition and Conference*. Society of Petroleum Engineers.

assessed. The injected chemicals must be in accordance with the OSPAR regulations (e.g., "Chemicals for Priority Action"). In all, since most of the injected solvents are of the same nature as the already produced hydrocarbons from the same platform and piping network, no extraordinary safety risk is expected. The *"solvent extraction of hydrocarbons in water and sediments"* is mentioned in the Brent GBS content technical document (Shell, 2017), but according to the publicly available documents not considered as one of the in-situ treatment options. The injection of steam could also be considered, as it was used in cleaning hydrocarbon phases from the equipment and piping system of the Frigg field[2].

Alternative 2: Extraction of the residue as froth

This technique, used in the mining industry, oil sand production, and deep sea mining (known as airlift, similar to the gas lift in oil production), requires injection of air and surfactant to create froth, trapping the sediment particles in water films. The froth can be transported through pipes to the platform and transported to the shore through a pipeline or in a ship. The pipelines are functional for fluid flow (Shell, 2017; page 88). Since these lines are used for transport of the produced hydrocarbon/(sea)water to and from the cells, it might be possible to use them for the injection of gas.

In both above-mentioned options, the transport to shore can be done by ship. The derogation report states that shipping extracted slurry with a 10:1 ratio of water/sand is possible by storing the slurry in tankers and shipping to land. A low safety risk is expected for this operation, on par with the safety risks of oil export operations from the same platform prior to the installation of the transport pipeline in 1988. The environmental effects of transport are limited to the CO_2 emissions from the shipping. The environmental footprint (land use, water consumption, chemicals and energy requirements) of the onshore treatment of the collected sediments is substantial as already discussed in the removal options in the Brent GBS contents decommissioning technical document.

Using Canadian oil sands as an analog for the above-mentioned residue (the oil and water contents are similar, but the oil composition is different in the residue), similar technology can be used for onshore treatment of the residue or the separated hydrocarbon phases. Selection of the right treatment method requires a thorough knowledge of the contaminants[3]. This helps to identify the compounds that are toxic to the aquatic biota and choose the best method to target those contaminants in terms of effectiveness of removal and environmental footprint. Currently, the contents of the GBS cells are not accurately known. Considering the current reported compositions, it is recommended to suggest a methodology involving adsorption, biological treatment (e.g., bioreactors), photocatalytic oxidation, and treatment ponds[4]. Given that many of

---

[2] Vivet S. (2011) Frigg Decommissioning Offshore Work. Offshore Technology Conference, 2011.
[3] Allen E.W. (2008) Process water treatment in Canada's oil sands industry: I. Target pollutants and treatment objectives. J. Environ. Eng. Sci., 7 (2), 123-138.
[4] Allen E.W. (2008) Process water treatment in Canada's oil sands industry: II. A review of emerging technologies. J. Environ. Eng. Sci., 7 (5), 499-524.

these solutions have not been fully assessed it cannot be concluded that a sufficiently comprehensive assessment of the cell content removal processes has been carried out.

Question 4: Preference of cell content management in terms of environment and safety

The cells of the three GBSs in the Brent field in total contain non-trivial amounts of contaminated sediments and water that Shell proposes to leave in place. The volume estimates and especially their oil and other pollutant fractions are uncertain, since only three non-random cells on a single GBS were investigated, and the (shallow) sediment samples taken were small compared to the sediment volume in a single cell. Estimating the volumes of the various pollutants in the cells thus requires significant assumptions in order to extrapolate results over all 42 oil cells on all three GBSs. Doing so, Shell uses average values from the three investigated cells, not conservative (higher) values as required by OSPAR Decision 98/3.

The timing and rate of GBS cell content release into the environment is highly uncertain. Not only is little known about the degradation of concrete and steel in a maritime environment over the course of centuries, but also the release can be initiated following an event that is impossible to predict, such as a severe storm or seismic activity centuries from now. The high uncertainty in timing and rate of cell content release adds another layer of complexity in predicting future environmental impact. Another source of uncertainty herein is the unknown future state of the local ecosystems in the Brent field, which could be more vulnerable, in which case Brent releases of contaminants may have larger impacts.

The environmental impact of release of the cell contents depends on the concentration and chemical characteristics of the material and the marine degradation products of the material. The analysis of the cell contents is limited to compound classes and certain main constituents, and thus there remains large uncertainty in the accounting for persistent and toxic degradation products.

Safety-wise, “remove” versus “leave-in-place” scenarios balance the risks to (present-day) Shell personnel with those to (future) stakeholders, which arguably is a difficult comparison to make. Moreover, the risks to personnel can be mitigated using technology. No party considers it technologically infeasible to remove all contaminants from the GBS cells.

In the CA made to determine the *“emerging recommendation”* for cell content management, all *“differentiators”* are internal to Shell and should be of little to no interest to the authority deciding on derogation. Removing “technical feasibility”, “cost” (highly correlated with technical feasibility) and “safety risk offshore personnel” as weighting criteria in determining the recommended scenario, which bear consequence only to Shell internally, it is found that “leave in place” is no longer the clear emerging recommendation for GBS cell content management, in which case derogation from OSPAR Decision 98/3 becomes hard to argue for.

The above argumentation is also valid for the contents of the GBS tri-cells and GBS legs, the drill cuttings piles on top of the three GBS caissons and around all four installations, even taking into account the environmental impacts of the recovery, transport, treatment and disposal of these, which are preferred to leaving the waste subject to uncertain processes in a likely unmonitored environment centuries from now. In order to reduce the uncertainty of future impacts, all above listed contaminants could be removed from the Brent field.

Question 5: Consideration of Best Available Technology

Shell has taken the state of the art as the basis for many of their investigations, including the re-floatation technologies for the GBSs, testing various cutting technologies for the GBS legs, developing a new tool for sampling the cells (although applied to a limited extent), and various methods for accessing the GBS cells and removing their contents. There are, however, several cases, for which the relevant technologies seem not to be investigated:

<u>In-situ remediation of the cell contents</u>
The bioremediation of the cells by injection of chemicals that enhances the biological reactions is considered and ruled out due to its (surprisingly) high safety risk and limited effect. However, Shell has only to a limited extent considered thermal remediation methods, such as injection of steam, as used in the Frigg field decommissioning. Since the cells are well-isolated from the surrounding cold sea, there is very limited heat loss, which potentially makes the process energy-efficient. This method does not require mixing since heat is transferred to the whole system by conduction. The heat also reduces the viscosity of the oil phase and might improve separation from sand, in which case it can subsequently be removed through the pipelines.

<u>Extraction of hydrocarbons from the cell contents by injection of chemicals</u>
Shell and its partners have objectively one of the best lines of research in the development of new chemicals and techniques for the recovery of residual oil, and in separating oil from sand. Yet the use of solvent for oil recovery from the GBS cells is mentioned only in one table and not evaluated further. Considering the pipelines that provide the possibility of injecting/circulating fluids in the cells (with modifications to the pumping system), the injection of hydrocarbon solvents, water-soluble solvents, surfactants, hot water, and steam should be investigated.

<u>Extraction of the sediments</u>
Techniques like frothing, which can be implemented for the removal of cell residue, are not considered by Shell. A similar technology, called airlift, is used in deep sea mining for the vertical transport of particles. This method can be implemented by the injection of compressed air into the ballast lines at the bottom of the cells to create well-mixed froth. If the viscosity of the oil phase in the sediment, which is not reported in the Brend derogation reports, is high, this method might require mechanical agitation and mixing. This can be addressed by increasing the temperature of the sediments to reduce the viscosity, or deployment of mechanical agitator by creating a large access hole through the cap. The later case increases the safety risk of this

operation, similar to the risk of option 2 (recover to shore and treatment) in the Brent derogation assessment report.

Cell and drill cuttings sampling
The development and deployment of the cell sampling tool are certainly technological achievements. However, the tool is only used to sample three cells on one platform based on their accessibility, and there are limitations, including limited penetration into the sediments, causing disturbances on the sediment surface, and mixing the residue samples with the interphase material and the attic oil. Based on these experiences gained between August and September 2014 during the sampling of the GBS cells, there was time for the improvement and re-deployment of the tools to take better and more samples from the cell sediments. After the removal of the Brent Delta topside the drawdown system does not need to be maintained, which means that creating large access holes in the cells does not threaten the stability of the structure, and providing the opportunity for deployment of heavier tools for deeper sediment sampling. Similar problems exist with the sampling of the drill cuttings piles, which possibly resulted in an underestimation of the amount of drill cuttings (currently not in agreement with the historical drilling data).

Simulation of contaminant release into the sea
The PROTEUS software that is used for the simulation of the oil release from the contaminated drill cuttings piles and GBS cell contents is not fit for purpose. Better solutions could have been realized by combining the state of the art simulators for the seawater flow and its interactions with the seabed and the advection-diffusion-reaction solvers. The documentation of the PROTEUS software shows that the model requires a value for surface oil loss rate as an input parameter, which makes it hard to believe that it is capable of predicting oil release rates. The IRG states that *“the modelling results can only be regarded as order of magnitude estimates”* and are to be considered as indicative rather than definitive.

Question 6: Justification of uncertainties

The IRG, and to a lesser degree also Shell, identified large uncertainties related to the Brent field decommissioning derogation, namely:

1. the uncertainty in the timing and manner of collapse of the installations, specifically the collapse of the GBS legs to depths at least 55 m below Lowest Astronomical Tide (LAT) and the breaching of the GBS cells exposing their contents,
2. the uncertainty in the timing and rate of release of contaminated materials in the GBS cells, tri-cells, legs and minicells, and potentially from drill cuttings piles,
3. the uncertainty in the quantities of contaminated materials in the GBS cells, tri-cells, legs and minicells, and in drill cuttings piles on top of and around installations,
4. the uncertainty in the environmental impact of contaminants, and their degradation products, in the GBS cells, tri-cells, legs and minicells, and in the drill cuttings piles,
5. the uncertainty in shipping intensity in the long-term future,
6. the uncertainty in commercial fishing activity in the long-term future,

7. and the uncertainty in the assumptions made in, and shortcomings of the CA balancing the advantages and disadvantages of the “leave-in-place” scenarios.

Sources of uncertainty 1, 2, 5 and 6, and to some extent 4, are inherent to “leave-in-place” scenarios in a project of this magnitude and with a multi-centennial timespan, and cannot be avoided. The largest differences in opinion in the reviewed documentation are about the uncertainty in the amount of contaminated materials (3), the suitability of the model used for environmental risk analysis (4), and the accumulation of uncertainties and assumptions made in the CA (7). Especially given the relative lack of factual knowledge of contaminated waste quantities, and the clear danger of bias in the CA in which currently criteria that are entirely internal to Shell and not of consequence to stakeholders are decisive, it has to be concluded that not all uncertainties in the various investigation reports are justified nor acceptable. It is noted that uncertainty sources 1-5 and 7 become largely or entirely irrelevant, and 6 is reduced by: removing all contaminated materials from the Brent field (2, 3, 4, 7), cutting the GBS legs to depths of at least 55 m below LAT (5), and removing the Brent Alpha jacket footings (6).

Question 7: Recommendations

1. It would be recommended to stay true to the “spirit” of OSPAR Decision 98/3 to the extent possible, not only because it avoids passing on potential problems to future generations, but also to prevent large amounts of negative public attention as was the case in the decommissioning of Brent Spar in the 1990s. A prudent way forward is to take everything except the GBSs out, including the Brent Alpha footings, GBS conductors and drill cuttings piles, and remove or remediate all contaminated contents from the GBS cell, tri-cells, minicells and legs, following the Frigg field DP1 platform decommissioning example. Remove legs (transport to land or leave on sea bed) to a depth below 55 m LAT as recommended in the “Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone” published by the International Maritime Organisation (IMO). Leave cells in open contact with the sea, proving that this poses no problem, and preventing potential issues to be passed on to future generations. Have a plan ready for future removal of the GBSs, if legislation changes. Monitor by 3D scan and chemical sampling in the years after. Allocate the money saved by not transporting the concrete structures onto land for developing or de-risking solutions for future decommissioning projects.

2. In making an effort to eliminate most of the large uncertainties that are inherent to an operation of the magnitude and time span of Brent decommissioning, one will find that removing all contaminated materials, removing the Brent Alpha footings, and placing the GBS legs on the sea bed (requiring a change in government policy) presents the most certain solution.

3. The Department for Business, Energy and Industrial Strategy (BEIS) should consider allowing GBS leg toppling (after drill cuttings pile removal) and placement on the sea bed, as this opens up a scenario with several considerable advantages in terms of risks to the users of the sea and environmental impact. Coincidentally, it provides an option that is cheaper than onshore disposal.

4. It is crucial in the derogation assessment that criteria that are entirely internal to Shell, such as cost, technical feasibility, and personnel safety (all of which are strongly correlated), are not taken into account in order to establish a weighting considerate of the stakeholders. The added decommissioning cost is small in comparison to the profits from the Brent field.

5. If it is allowed to leave the GBS cell contents in place, it is preferable to gradually release the cell contents in the coming years as opposed to a potential sudden release with unknown consequences in the distant future. Doing so, not only is fast release avoided, but also the impact can be monitored and affect future decision-taking.

6. It could be considered advantageous to assess different aspects of derogation in separate reports. Currently, some important aspects of the decommissioning are at risk of being overlooked due to the large amount of information provided, such as the numerous conductors, or the Brent Alpha footings.

7. If a Brent decommissioning derogation permit is extended, it could be a temporary one, requiring reapplication upon expiration. An advantage would be that if technologies required for removal currently do not exist, they may have been developed (changing the Best Available Technology) before a future permit application.

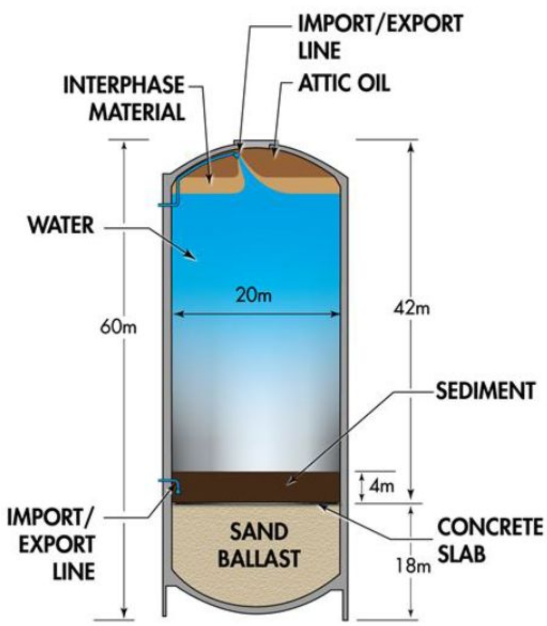
Annex 1: Supplementary material

Question 2 (Annex)

Notes and highlights from the Brent Decommissioning Derogation Assessment relevant to Question 2:

Page 166: *"The three cells that were sampled were chosen on the basis of their accessibility because the sampling equipment had to be deployed from the overhanging topside. It is believed that the cells accessed during the CSP were likely to be representative of the other Delta oil storage cells because the accumulation of sediment is a long-term process spanning at least two decades and thus short-term differences in operation are not likely to have a significant effect on the sediment volume and composition. The Delta samples are also believed to be representative of the other two platforms Bravo and Charlie because they are producing from the same reservoir using the same process and a similar suite of production chemicals."*

Page 164:



Page 166: *"The cells which were sampled were ones that had been 'displaced to water'. This means that the final export of oil from them had been completed and that they were filled with a mixture of seawater and produced water, and because they no longer contained recently produced crude oil all their contents were at the same temperature as the seawater around them. The sampled cells thus exhibited the four types of materials – attic oil, interphase material, cell water and cell sediment – of a 'typical' oil storage cell after CoP shown in Figure 57, and they also provided information about the physical and chemical state and composition*

of those materials once they had cooled to ambient temperature. In total, the CSP collected 9.6 litres of water and 6kg of cell sediment."

Page 165: *"Table 25 presents the co-venturers' current (post-CSP) estimates of the amounts of various materials that are present in the Brent GBSs, before the removal of any attic oil and interphase material, excluding the sand ballast and concrete diaphragm in the Bravo and Delta cells, and the structural steel and pipework in the legs. In total this amounts to approximately 639,000 tonnes of oily water and approximately 66,000 tonnes of solids (if the average specific gravity of the solids is 1.5)."*

Page 167: *"Sonar mapping: The cell contents of the three cells on Delta were mapped using a 3D sonar which was designed to identify the boundaries between the different layers of attic oil/interphase material, water and sediment. The sonar was deployed through a new 3 inch sub-sea access, drilled through the cell-top. The results from the CSP found 852m^3, 1,185m^3 and 1,095m^3 of sediment in the three cells (average 1,044m^3), which equates to depths of 3.2m, 4.4m and 4.1m respectively, with an average depth of 3.9m. This provided some validation of the earlier assumptions on which a range of other desk-top studies, dispersion modelling and ecotoxicological assessment had been based."*

Page 49: *"On Delta, the oily material lying at the bottom of the minicell annulus was sampled using a gravity core, and this identified the interface between the contaminated material and the sand ballast below. It was found that the contaminated material was between 0.6m and 1.2m thick, corresponding to volumes of 135m^3 and 270m^3 respectively (approximately 160 tonnes to 320 tonnes). For the purpose of the assessment of management options for this material, it was assumed that there was 250m^3 of material in the minicell annulus. On Bravo, the cores did not establish the depth of this interface, and for the purposes of CAs it has been assumed that the total amount of material in the Bravo minicell annulus is the same as that in the Delta minicell annulus. The estimated volumes of material in the minicell annulus on Bravo and Delta are shown in Table 37."*

Table 26 Comparison of the Analytical Results from the Brent Delta CSP Water Samples and the Pre-CSP Initial Assumptions.

Parameter	Brent Delta Assumptions in Original Modelling	Results from CSP Cell Water Sampling				
		Average of CSP Samples	Cell 9 Average	Cell 17 Average	Cell 18 Average	Maximum Value in CSP Samples
Average Density (kg/m³)	1,019	1.022	1.022	1.022	1.022	1.023
Chemical concentrations (mg/l)						
Mercury	0.0022	0.0020	0.0019	0.0032	0.00079	0.012
Copper	0.33	<0.16	<0.16	<0.16	<0.16	<0.16
Zinc	2.568	<1.2	<1.2	<1.2	<1.2	<1.2
Naphthalene	0.496	0.027	0.040	0.036	0.0058	0.044
Benzo(a)pyrene	0.052	<0.0009	<0.002	0.0005	<0.0001	<0.002
Phenanthrene	0.198	0.0096	<0.002	0.024	0.003	0.026
Benzene	112.8	3.386	1.307	7.25	1.6	8.6
Total PCBs	0.012	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
TPH	503	417.8	33.5	1,081	139	1,380
Tributyl tin	0.00008	<0.0004	<0.001	<0.0002	<0.0001	<0.001
Phenols	0.474	1.2	<0.3	2.08	1.22	0.33
Organic acids	876	6.13	2.2	7.6	8.6	8.7

Table 28 Comparison of the Results for the Chemical Composition of the Brent Delta CSP Sediment Samples with the Pre-CSP Initial Assumptions.

Chemical Name	Brent Delta Pre-CSP Initial Concentration (mg/kg)	Brent Delta Pre-CSP Worst Case Initial Concentration (mg/kg)	Results from CSP Cell Sediment Sampling (mg/kg)	
			Average Concentration of CSP Samples	Maximum Concentration in CSP Samples
Mercury	4.164	12.5	0.152	0.3
Copper	1,118.4	3,355.2	42.25	84.0
Zinc	2,028	6,084	84.3	170
Naphthalene	301.2	903.6	30.2	56
Benzo(a)pyrene	171.6	514.8	0.4	0.60
Phenanthrene	913.2	2,739.6	14.3	27
Benzene	1,010.4	3,031.2	1,122	1,240
Total PCBs	0.12	0.36	<0.001	<0.001
TPH	110,000	330,000	152,120	175,000
Tributyl tin	0.256	0.768	<0.0001	<0.0001
Phenols	82.68	248.0	79.8	161
Octylphenol	Note 1	Note 1	0.0504	0.0575
Nonylphenol	Note 1	Note 1	0.833	0.912

Note: 1. Octylphenol and Nonylphenol were subsequently modelled after the CSP sediment sampling.

Notes and highlights from the Brent GBS Contents Decommissioning Technical Document (Shell, 2017) relevant to Question 2:

Page 47: *"The detailed analytical results are presented in Appendix 4. The common trends emerging from the overall set of results reveal that these samples are a mixture of sand, water and hydrocarbons. The ratio between the phases varies but the samples taken inside the equipment closest to the storage cells (Brent Spar and topsides separators) are close to a ratio of 1/3 sand, 1/3 water and 1/3 hydrocarbons. The chemical analyses carried out on those samples indicated the presence of the expected contaminants, namely petroleum hydrocarbons and associated heavy metals. Apart from the petroleum hydrocarbons, the contaminants of concern in these samples were Mercury and Naturally Occurring Radioactive Material (NORM). High levels of NORM activity were found in the Brent Spar samples but low levels were measured in the Delta topsides separators, so there is significant uncertainty about the actual level of activity within the storage cell sediment. Low levels of NORM were also measured on the samples from the storage cells collected in 2014 (refer to Section 9.4)."*

Page 60: *"Traces of octylphenol and nonylphenol have been detected in the sediment samples of Cell 17 and Cell 18. These compounds were present in some chemicals used in the offshore industry, such as emulsifiers, before being phased out in the early 2000s following their addition to the OSPAR list for priority action."*

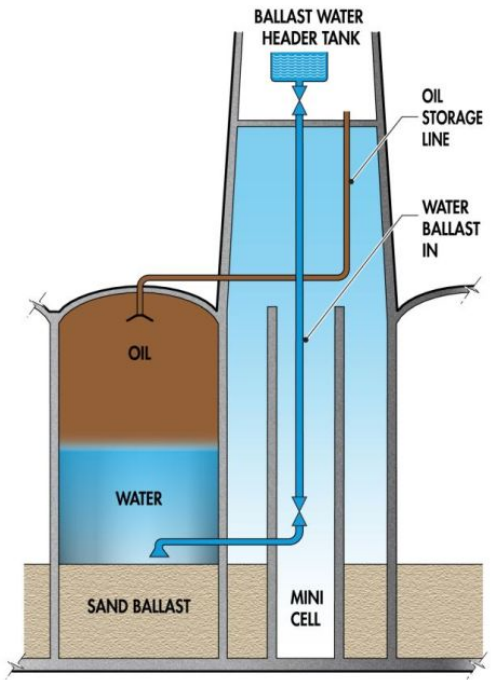
Page 287: Statement that the environmental effects on the water column are localized and temporary: *"As the GBS caissons degrade, the concrete from the walls of the outer cells would be likely to fall on to the existing seabed drill cuttings. Estimates suggest that, barring large-scale damage, it might take about 500 years for the caisson walls to weaken and collapse.*

Although it was predicted that the seabed drill cuttings would still exist at this time, the total amount of hydrocarbon contamination in them, and the area of affected seabed, will both be less than at present. Although each impact would disturb the drill cuttings, the environmental effects on the water column and seabed would be both localised and temporary."

Question 3 (Annex)

Notes and highlights from the Brent GBS Contents Decommissioning Technical Document (Shell, 2017) relevant to Question 3 (and 5):

Page 22: Figure 7 shows the general arrangement of drawdown system and the piping system that goes into the cells (see also Figure 10).



Page 46: The estimated volume of the cell sediment is uncertain due to the incompleteness of the production history (only data from the last 10 years of production) and the lack of measurements of the sand concentration in the produced fluids.

Page 52, Table 13: Oil diffusion coefficient = 0.3 cm^2/year = 9.5×10^{-13} m^2/s; this value is <u>too small</u> if it describes the diffusion of oil in water. Oil leaching rate; it is not clear how the assigned values to this parameter are determined and how this affects the prediction of the oil release rate.

Page 60, Table 18: The concentration of organic acids in the oil content of the sediment is not measured. When dissolved in water, organic acid is acutely toxic to aquatic biota.

Page 61: Particle size distributions of the particles are centered on the range of 100 to 400 micrometer.

Page 84, Table 30: In-situ treatment: solvent extraction of hydrocarbons in water and sediment.

Page 88: From the report by Aker Kvaerner that studies the existing pipework of the GBS cells, it is found that:

- *"The pipework is in place and accessible via the utility leg"*
- *"There are existing operational procedures and experiences for working down the utility leg"* that can *"reduce the amount of subsea activities required"*.
- The disadvantages are the risk of H_2S poisoning if personnel work down the utility leg, equipment cannot be deployed via the pipelines, the topside needs to be in place to break into the pipework from a lower level.
- *"The existing pipework could be used to pump fluids to and from the storage cells"*

Page 91: Drilling a large hole into the cell top is technically challenging and associated with major safety risks.

Page 99, 100, 101:

- *"The sediment slurry and/or fluids could be shipped back to shore"* on medium-sized shuttle tankers.
- Centrifuge-separation for separating the fluids from the contaminated sand
- Thermal desorption to evaporate the organic compounds from the sand, which is effective but very energy intensive.
- Incineration which is prohibited by OSPAR. It is not clear why a prohibited technology is even considered.
- Direct chemical oxidation (in-situ) which is not possible due to the lack of mixing and agitation in the cells. It shows, however, that there is a possibility of injecting chemicals into the cells.
- Biological treatment, which is described extensively, but has the exact same issue as the chemical oxidation. It is not clear why an ineffective option is even considered with the very low temperature that is not suitable for microbial activities and the diffusion-limited transport of the chemicals into the sediments.

Page 108, 109:

- *"The use of the existing pipework cannot be completely excluded"*
- *"Fluids could be injected inside the storage cells via the existing pipework"*
- Injected fluid might flow into other cells as well.
- *"Fluids could also be displaced through the water ballast system using the produced water pumps"* with some modifications since these are not designed for this purpose.
- The extraction system is designed to pump only hydrocarbons (with a lower density than water). For the extraction of other fluids, the pumps needs to be replaced.
- *"The existing pipework is in a poor or unknown condition. It cannot be used as it is to support remediation activities. Modification and reinstatement would be required to make it suitable for use"*. This statement is in direct contradiction with several other statements about the possibility of using the piping system for pumping fluids. Also, these modifications were never considered as an option.
- Several studies on cell content mobilization are not publicly available.

Page 112, 113, 114: Topside treatment is ruled out as it has a high power requirement of 3.1 MW peak electricity demand and a 5.1 MW heat. However, by using a Combined Heat and Power (CHP) system, the waste heat from the generator can be used in the treatment units.

Page 115, shortlisted options: *"As a result of the technical feasibility studies and screening …, five options for the management of the cell sediment were studied further and take forward for full CA"*. This statement is not accurate, since none of the insitu options were ruled out but only required some modifications in the existing piping systems. The considered options, however, required major sea operations to create access holes in the cells cap.

Page 137, degradation of GBS caisson: *"It is acknowledged that due to lack of data and the long time-scales involved, it is impossible to estimate exactly how long the GBSs will survive, or how soon they may begin to fail, or exactly how they may fail."*

Question 4 (Annex)

The Brent Decommissioning Derogation Assessment report (Shell, 2018) provides the following information on the types of waste in the GBSs (excluding the drill cuttings on and around the installations).

Page 41: *"Several types of material are known to have accumulated in the GBSs during their operational lives. These are: (i) the oily sediment in the bases of the former oil storage cells; (ii) the oily material in the bases of the two drilling legs on both Bravo and Delta; (ii) the oily material in the base of the minicell annulus, the space between the wall of the minicell and the wall of the utility leg, on Bravo and Delta, and; (iv) drill cuttings in the tri-cells on Bravo and Delta."*

Specifically about the GBS cell contents: *"Note that all attic oil and interphase materials will be removed"*, although Shell does caution the reader that they may not entirely succeed in doing so.

Page 166:

Table 25 Estimated Volumes of Materials in GBS Cells.

Material	Bravo	Charlie	Delta	Total
Attic oil (m^3) (Note 1)	0	11,116	800	11,916
Interphase material	ND	ND	ND	ND
Oily water (m^3) (Note 5)	164,416	311,667	163,616	639,699
Oil within the water (Te) (Note 2)	68	130	68	266
Cell sediment (m^3) (Note 3)	16,704	6,035	16,704	39,443
Oil within the sediment (Te) (Note 4)	4,665	1,686	4,665	11,016
Minicell oily material (m^3)	250	0	250	500
Drilling leg oily material (m^3)	2,000	0	2,000	4,000

ND = No Data

Both the IRG and Scientia et Sagacitas state repeatedly that too little information is available on the cell contents, that it is highly uncertain when and how the surrounding waters will be exposed to the cell contents, and that the used modeling tools are inadequate for determining the environmental consequences of release:

IRG report, page 4: *"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."

IRG report, page 23: *"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."

IRG report, page 27: *"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."*

IRG report, page 27: *"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."*

IRG report, page 28: *"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."*

IRG report, page 28: *"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."*

IRG report, page 29: *"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. [...] 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. [...] 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."*

IRG report, page 31: *"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."*

IRG report, page 31: *"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."*

IRG report, page 34: *"[...] Shell and its contractors [...] 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."*

Scientia et Sagacitas report, page 11: *"The quality of the base data used impacts all subsequent engineering and environmental analysis works throughout the project [...]. The base data made available as a result of sampling operations is very limited in both quantity and quality. [...] Brent Bravo and Brent Charlie Storage Cell inventories are 'assumed' with no factual evidence to support the assumptions. Brent Delta inventories are 'extrapolated' from 3 poor cell sample results across the remaining 13 cells. The Brent Delta results were then further unjustifiably extrapolated across the other CGBS storage Cells on Brent Bravo and Charlie. Even Shell/Exxon indicate this is a concern in their documentation but then appear to ignore the implications. [...] Without a proper assessment of the volumes and nature of the materials inventory in the storage cells it is not possible to identify, with confidence, the necessary works to recover/remove inventories. For example, Interphase material volumes have not been mapped, so there can be no confidence in any estimates of what removal operations will really be required. As such, there are concerns about the use of indicative/assumed data in the CA* *process, thus introducing significant levels of uncertainty into the process with accompanying bias into scoring exercises and ultimately the 'preferred options'."*

Scientia et Sagacitas report, page 28: *"The above ranges in data, and complete lack of physical data for Brent Bravo and Brent Charlie cell contents mean that is it not possible to say with confidence that extrapolating results from mapped cells across the 3 CGBS structures is a fair and valid approach to cell mapping and cell content volume calculations."*

The IRG considers Shell's approach in the Comparative Assessment procedure intransparent in places, and the outcome of the recommendation to be sensitive to the weighting of the options:

IRG report, page 10: *"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, 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."*

Shell's five short-listed options for the management of GBS cell contents are the following:

Shell report, page 172:
"1. Recover and Re-inject. The entire contents of the GBS storage cells would be completely removed as a slurry of sediment and water, and the recovered material would be disposed of into new remote subsea wells created solely for this purpose.
2. Recover and treat onshore: The entire contents of the GBS storage cells would be completely removed as a slurry of sediment and water, and the recovered material would be taken to shore for treatment. The oil would be reused, and inert solids disposed of to landfill.
3. Leave in place and cap: The cell water would be treated with chemicals to reduce the concentration of hydrocarbons. A physical barrier ('cap'), probably comprising a layer of sand, would be created on top of the sediment in each cell to minimise the potential dispersion of sediment when the GBSs collapse.
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 GBSs collapse.
5. Leave in place: Both the water phase and the sediment phase would be left in place in the cells, untreated, after the removal of any attic oil if present."

Shell finds that option 5 (Leave in place) of the Comparative Assessment of GBS cell contents management is the emerging recommendation:

Shell report, page 175:

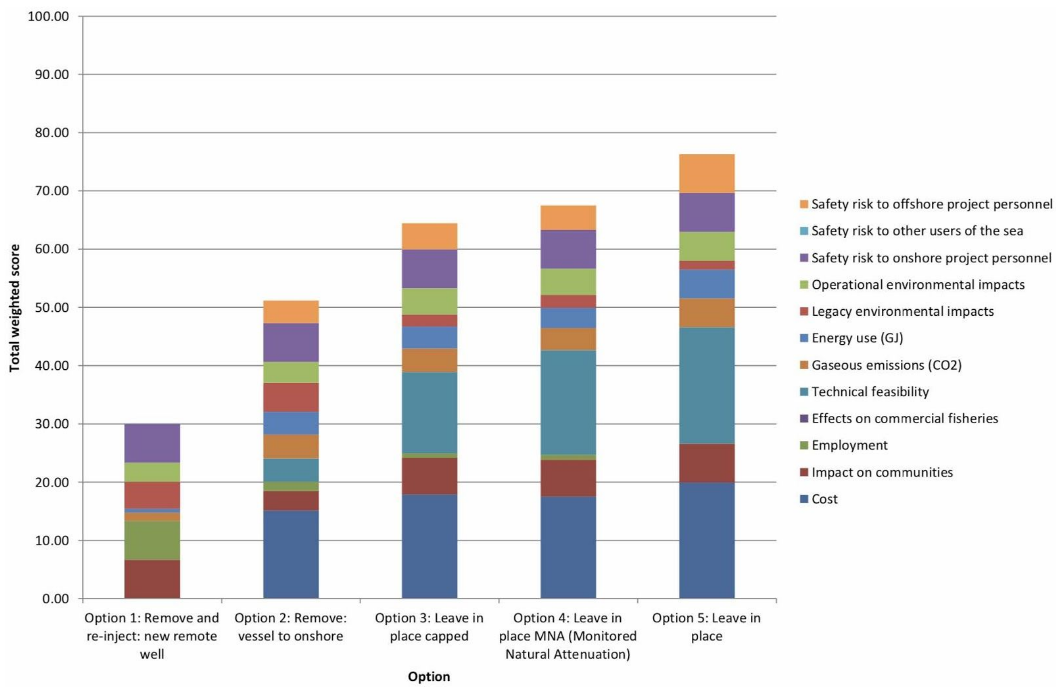
Option 1	Remove and re-inject in new remote well
Option 2	Remove and treat onshore
Option 3	Leave in place capped
Option 4	Leave in place with MNA
Option 5	Leave in place

Table 30 Transformed and Weighted Sub-criteria Scores for the Five Options for the Brent Delta Cell Contents.

Sub-criterion	Options				
	1	2	3	4	5
Safety risk offshore project personnel	0.00	3.89	4.50	4.21	6.66
Safety risk to other users of the sea					
Safety risk onshore project personnel	6.67	6.64	6.67	6.67	6.67
Operational environmental impacts	3.25	3.60	4.50	4.50	5.00
Legacy environmental impacts	4.65	5.00	2.05	2.20	1.50
Energy use	0.66	3.89	3.81	3.49	4.93
Emissions	1.42	4.09	4.01	3.76	4.93
Technical feasibility	0.00	4.00	14.00	18.00	20.00
Effects on commercial fisheries					
Employment	6.67	1.63	0.71	0.83	0.03
Impact on communities	6.67	3.34	6.34	6.34	6.67
Cost	0.00	15.12	17.86	17.50	19.90
Total weighted score	29.99	51.19	64.45	67.51	76.30

Note: High values for the sub-criteria assessed as 'scores' indicate good or desirable performance.

"On the basis of this assessment, the 'CA-recommended option' for the Brent Delta cell contents is Option 5 'Leave in Place'."



"In all six of the scenarios, the order of the five options does not change as a result of the changes in weighting. Option 5 'Leave in place' always has a higher total weighted score than the next best option"

Similarly, Shell finds that the "leave in place" option is recommended for the contaminated materials in the drilling legs:

Shell report, page 186: *"On the basis of this assessment, the 'CA-recommended option' for the material in the Brent Delta drilling legs is Option 5 'Leave in place'. [...] In all six of the scenarios, the order of the five options does not change as a result of the changes in weighting. Option 5 'Leave in place' always has a higher total weighted score than the next best option. [...] The co-venturers have concluded that, for both Bravo and Delta, the significant sub-criteria serving to strongly differentiate the options are 'technical feasibility' and 'cost'."*

Similarly, Shell finds that the "leave in place" option is recommended for the contaminated materials in the minicell:

Shell report, page 195: *"On the basis of this assessment, the 'CA-recommended option' for the material in the Brent Delta minicell annulus is Option 5 'Leave in place'. [...] In all six of the scenarios, the order of the five options does not change as a result of the changes in weighting. Option 5 'Leave in place' always has a higher total weighted score than the next best option. [...] The co-venturers have concluded that the significant sub-criterion serving to strongly differentiate the options is 'technical feasibility'. The only credible and realistic way of gaining access to the material in the minicell annulus would be through a large hole cut in the side of the leg. This would enable a work-class ROV to enter the leg and create access through decking and pipework so that hoses and suction dredgers could be deployed remotely onto the layer of* *material lying on top of the and ballast in the annulus. Such operations have not been performed before and would require a considerable amount of planning and testing before they could be executed safely and with a high likelihood of success."*

Similarly, Shell finds that the "leave in place" option is recommended for the drill cuttings on top of the GBS cells, although initially modeling results indicated an oil loss to the ocean exceeding acceptable limits:

Shell report, page 199: *"For the Brent Bravo and Brent Delta cell-top drill cuttings piles it was concluded that the oil loss rate and area persistence were below the OSPAR 2006/5 thresholds and that these drill cuttings piles should, as far as possible, be left in situ to degrade naturally. Modelling of the Brent Charlie cell-top drill cuttings pile (the largest of the cell-top piles and more than twice the volume of either the Bravo or Delta cell-top pile) showed that this pile exceeded the oil loss rate threshold. The Charlie cell-top pile was therefore subjected to a Stage 2 assessment which concluded that this drill cuttings pile should also be left in situ to degrade naturally."*

Similarly, Shell finds that the "leave in place" option is recommended for the drill cuttings in the tri-cells, although initially modeling results indicated an oil loss to the ocean exceeding acceptable limits:

Shell report, page 199: *"As with the cell-top drill cuttings, these tri-cell drill cuttings have been considered under OSPAR Recommendation 2006/5 because they would have contributed to the seabed drill cuttings piles if not for the physical presence of the GBS caissons. Drawing on the long-term fate modelling already conducted for the Brent Field drill cuttings and the 2015 tri-cell sample data, it has been concluded that the tri-cell drill cuttings fall under the OSPAR 2006/5 thresholds for oil loss rate and area persistence [...] and should be left in situ to degrade naturally."*

Shell report, page 286: *"Using the maximum THC to represent the whole cell-top drill cuttings pile, the long-term fate modelling indicated that the initial cell-top drill cuttings pile oil loss rate [...] and therefore the initial combined cell-top and seabed accumulations oil loss rate [...] would exceed the OSPAR oil loss rate threshold [...]. As required under OSPAR Recommendation 2006/5 a Stage 2 assessment of potential management options for this drill cuttings pile was completed, and this concluded that the drill cuttings pile should remain undisturbed. If some form of disturbance is required, for example to execute another required decommissioning work-scope, then the Charlie cell-top drill cuttings would be removed and taken to shore for treatment and disposal."*

Shell indicates that shallow coring gives oil content values that are not representative of the deeper sediment layers:

Shell report, page 292: *"Samples retrieved in 2015 from the Delta tri-cells indicate that the maximum concentration of oil in these drill cuttings is 9.2%, although it should be noted that the samples could only be taken from the upper, most probably more weathered layers of the drill* *cuttings. If this proportion of oil is representative of the tri-cell cuttings as a whole, it would be less than the average proportion of oil found in the CSP samples of the cell sediments (17.5%) [...].”*

Shell mentions that although emphasis in the report goes out to hydrocarbons, there are other pollutants in waste materials that have high persistence levels:

Shell report, page 303: *“The cell water, the cell sediment and in drill cuttings (in any location) contain a range of contaminants including hydrocarbons, other organic materials, and heavy metals. Hydrocarbons represent by far the greatest proportion of contaminants in all these materials, and they will be the main focus in the discussions below concerning the effects of contamination. It is noted, however, that although other contaminants may be present in much smaller quantities and at lower concentrations, they are not all amenable to chemical degradation or biodegradation, and once exposed may persist in the environment for a long time.”*

Scientia et Sagacitas report, page 33: *“Given recent advances in cutting techniques and deep-water mining and with the appropriate data sets and the volume of engineering/ risk mitigation works, it is considered that safe and full recovery of the cell contents is a potentially viable solution, although it will undoubtedly be a costly, time-consuming activity set. Here the relevance of the ‘precautionary principle’ and ‘polluter pays’ principles comes into play, given the long-term nature of the disposal proposals for these inventories. [...] It is unlikely that these operations will result in risk levels above normal operational risk acceptance limits, if they are engineered up properly.”*

Scientia et Sagacitas report, page 34: *“The use of any CA process for decisions relating to the management of CGBS Storage Cell Contents requires full re-consideration. Ideally, Inventory Full Removal should be required, unless it can be clearly demonstrated that it is technically infeasible, or safety risks are beyond acceptable parameters.”*

Question 5 (Annex)

IRG's purpose is to verify the reliability of the assessment methods, not to support or oppose the final weighting and balancing of the options (which is the responsibility of the operator). They used a bottom-up approach, i.e., first studying the technical document and later evaluating the technical policy that relies on the outcome of the technical activities. These are the important notes from the IRG report:

Page 2:

- Considerable uncertainties in many of the calculations and estimations.
- The decision is based on a trade off between high cost and technical difficulties versus limited environmental benefit (which is based on very uncertain estimates); a safety risk for personnel (calculated based on the internal indicators of Shell) that is much higher than the accepted risk of work in marine operations.

Page 3:

- Based on the current estimates, 5600 m^3 of oil in the drill cuttings is already exposed to the marine environment, and another 16000 m^3 will be exposed if the cells degrade and fail. This is comparable to the Exxon Valdez oil spill of 41,000 m^3. IRG notes that based on very uncertain calculations, the risk of oil release is local and unsubstantial (2-3 km).
- Sound arguments for the decommissioning of the pipelines.
- Removing the contents is likely to cause more pollution than leaving them in place (considering the 5 options studied by Shell).
- Reinjection was initially promising, but too many problems with injection into the available reservoir layers.
- Removing the GBS legs is difficult and unsafe. It is advisable to leave them in place although there is no reliable evidence on the long-term fate of the GBS legs.
- The legacy risk to the future users of the sea can not be determined even with orders of magnitude uncertainties due to:
  - Limited knowledge on the mode and rate of degradation of the concrete structure
  - The nature and frequency of the future marine activities
  - The effectiveness of future collision avoidance procedures (which is effective now)
- Suggestions:
  - reevaluation of the risks to shipping every decade
  - Preparation of Shell and partners for leg removal in the foreseeable future

Page 4:

- Uncertainties with the cell contents and drill cuttings:
  - Not enough samples
  - Mode, rate, and time of oil release
  - Using the inappropriate modeling tools (although expected by IRG to give similar outcome)

    - Suggestions: more (frequent) sampling and monitoring in the future
- Suggestion: update the policy to allow toppling of the concrete legs
- Shell has prepared no detailed program for monitoring the structures in the future

Page 6: IRG's purpose is to verify the reliability of the assessment methods, <u>not to support or oppose the final weighting and balancing of the options (which is the responsibility of the operator)</u>

Page 10: Cell Contents Management Stakeholder Task Group (CMSTG) participated in a detailed Multi-Criterion Decision Analysis (MCDA) of the options for cell contents decommissioning; <u>but the results of this study was not used for the selection of the final option. Shell used an alternative MCDA prepared internally. IRG does not know to what extent Shell's scoring and weighting of the options was influenced by the CMSTG report.</u>

Page 11: GBS peer review workshop: *"even though not proven, leg removal appears to be feasible"*

- Cutting technology needs to be tested in the field (for which shell conducted investigations)
- Lifting requirements to be studied

Page 12:

- None of the platforms were designed for eventual removal (fortunately, this is addressed in the new OSPAR decision for future platforms)
- Even if it was possible to remove the platforms, there is
    - Almost no reuse option <u>(for the concrete platforms)</u>
    - No cheap/low footprint technology for recycling or disposal (<u>again for the concrete</u>)

Pages 13 and 14, Brent Alpha steel jacket:

- Both partial and full removal options are feasible
- No comment on the preferred option by IRG since it is outside its brief
- The evidence and the analyses are sound
- The decision of leaving the footings in place is based on the internal CA of Shell with their own weighting and scoring of the criteria and options (<u>see page 10 on IRG's position on the internal weighting and scoring used by Shell</u>)

Page 15, Brent Bravo and Delta: *"The evidence used to reach the decision was soundly based"*

Page 15, Brent Charlie:

- Possible to re-float, but many uncertainties regarding the success of the operation.
- No re-float decision based on health and safety prospects, and project failure risk.

Page 16:

- Fishermen prefer the residual structures to remain visible (<u>will be a problem after the degradation and collapse of the topside in the future</u>).

- *"Reinforced concrete has only been in use for less than 160 years"*. Therefore, there is limited data to verify the models and simulations of degradation.
- Controlled toppling is against the government policy (can be changed).

Page 17 and 18, safety risk to the users of the sea:

- The splash zone of the GBS is likely to degrade first and the top part of the leg collapses (after 150-250 years)
- The bottom part (which is likely under the sea level and not visible) remains intact for an unpredictable number of years. Since it is hidden under water, it poses a great danger to shipping activities.
- Cutting the legs might require support and favorable weather conditions
- Lifting the pieces is possible by hooks in holes drilled into the legs
- <u>High potential loss of life for cutting the legs (based on internal Shell indicators), but it can be mitigated to an acceptable level as per Shell's own suggestion</u>
- Extremely large uncertainties on risk to the future users of the sea, since it is very difficult to extrapolate current data to the sea activities in the future (IRG has used underlined "extremely" in its report)
- Difficult to find a balance between the long-term risk of serious consequences to the users of the sea versus the short-term safety risk to the personnel
- *"<u>The legs may need to be cut at some future time, and the adequate provision for this eventuality should be made as part of the decommissioning programme</u>"*.
- Shell's decision was soundly based *"<u>except for the long-term risk estimates relating to the legs up/legs down options</u>"*.

Page 18 and 19:

- Several sampling attempts in 1977, 1986, 1990, 2006, 2007, and 2015.
- Lack of sampling from the seabed close to the platforms .
- The quality of the data is generally good, but the chemical analyses and data evaluation procedures were not appropriate or not optimal in some cases, although the suggestions were adapted by Shell to improve its methods.
- 2007 survey was less complete for the benthic fauna (focused more on chemical conditions).
- 2007 survey: absence of core samples from deeper cuttings piles on the sea bed
- 2015 survey: core taken from deeper layers, which shows higher contaminations due to the use of diesel-based drilling mud.
- IRG found the data to be incomplete but sufficiently representative for modeling if the drill cuttings (<u>not to forget that the model was not even designed for these systems</u>).
- In 2015, THC level exceeded 50 mg/kg (the OSPAR limit) in stations out to 300 m distance.

Page 20 and 21:

- The amount of estimated drill cuttings is significantly lower than the one from the drilling records.

- 2017 survey: cuttings pile close to the platform had THC levels up to 10%, close to the former regulatory limit for discharge of oil-based cuttings.
- 2015 survey (limited data): THC contents of around 5%.
- 2011 survey, cell top cuttings of Brent Charlie: 8-20% THC, in one case 33%.
- Other numbers (6-9% for Delta, 6.9-4.3% of only one sampled Delta tri-cell), indicating high uncertainty in the THC content.
- Metal concentration were in general above the OSPAR limit (in the cuttings), but decreased with distance from the platform.
- The sampling of cuttings piles are still not reliable, and IRG has suggested new sampling to reduce the uncertainty (IRG notes that the assumptions in the model -that are not themselves necessarily fit for purpose- most likely represent a worst case scenario).
- Tri-cell cuttings information in Bravo and Delta is incomplete because of the difficulty of sampling.

Page 21 and 22, modelling of the drill cuttings:

- Major issues:
  - Old and simple algorithms
  - Uncertain spatially variable input parameters
  - No validation
- Modeling is based on data from Alpha (steel jacket) and Charlie (GBS), which shows 40-50% of loss of cuttings volume and oil content due to spreading and erosion after 1000 years.
- Oil release rate is less than 10 tonnes/year which is the OSPAR threshold. For the worst case scenario defined by 333 g oil/kg cuttings, 14-16 tonnes/year oil release is determined.
- Due to the large uncertainties, IRG recommends the results to be regarded as indicative rather than definitive.

Page 22 and 23, cells and legs content:

- Initial estimation of the cell contents by analyzing surrogate samples from separators and onshore storage tanks.
- The residue contains sand with a small silt and clay fraction varying from 5-20% between cells (similar to oil sand).
- Only three of the 16 cells are sampled. The cells are chosen based on accessibility. Large variation between the cell contents is observed (e.g., from 13% to 39% of oil by volume).
- Much greater variations observed between the hydrocarbon content of water samples (30 to 1081 mg/l).
- Despite the considerable effort that is required to obtain and analyse the samples, the information gained from the sampling is very limited:
  - Only three cells on one platform.
  - Sample from the top several decimeters (out of 4 meters of sediment).
  - Disturbing the sediments during sampling.

    - Commingled samples; therefore no vertical profile of the contents.
    - Large variation between the measured contaminant concentrations in different cells.
    - Samples are contaminated with the attic oil and interphase material during the transport.
- Particle size of the sand: 100-400 micrometer.
- Except for BTEX and total HC, the measured concentration of all the contaminants in the samples are lower or much lower than the initial estimations based on the surrogate samples.

Page 25, 26, 27, cell content management:

- The technically less-challenging options of creating small access holes to liquefy and remove the sediments were <u>not viable.</u>
- <u>The CMSTG assessment work (not available publicly) for evaluating the five suggested options found different results than the internal assessments of Shell, e.g., under certain consideration the “remove and process onshore” became the preferred option.</u>
- Shell used the CMSTG results to inform their own considerations of the technically feasible options. Although there is no detail of their method of adjusting the weighting and scores.
- IRG considers further sampling of the sediments to be desirable.
- <u>Shell has not prepared any detailed monitoring program</u> based on the current exposure scenarios which is likely to happen much later in the future.

Page 28 and 29, cell sediment model:

- A slightly modified version of PROTEUS software was used. <u>A quick look at the documentation of the software shows that it needs the surface loss rate as an input parameter, which makes it hard to believe that is is capable of predicting the oil release rate</u>.
- IRG states that *“the modelling results <u>can only be regarded as order of magnitude estimates</u>”*, although <u>surprisingly</u> IRG concludes that the results *“<u>can be considered adequate as a basis for assessing</u> the likely environmental impact of the cell sediment release”*.
- <u>The adverse impact</u> on the sea bed is local but <u>may persist for several decades</u>.
- <u>Shell has only modeled the possible sudden release of 20 m^3 of oil</u> which shows a small impact. However, if three cells collapse at the same time, possibly 400 m^3 of oil can be released with potentially much larger disastrous environmental impacts.

Page 29, cell water release:

- IRG states its concern with the simulation results due to:
    - Questionable change of parameters during different phases of modeling.
    - Surprising features in the cell water dilution pattern from the simulation results (<u>note that the simulator is by no means designed for this purpose</u>).
- *“IRG considers the PROTEUS and other modelling results to be indicative only”*.
- Page 29, 30, fate of cell contents.

- Chronic PNEC (potential no effect concentration) level is limited to a few days and few km^2, based on the order of magnitude modeling results.
- Previous experiences suggest that after the release of oil from the “drill cuttings” (not the sediments), the *“full benthic fauna recovery will be in the range of 5-10 years”*.
- There is large uncertainty on the environmental impact of the oil release but the broad conclusion of limited areal impact would not change, although the time scale of impact might be extended.
- In relation to long term effect, the scientific/engineering/other evidence used to reach the “leave in place” conclusion are very uncertain but adequate to reach this decision.

Page 30, pipelines: The results of the CA that has led to the current conclusions are very sensitive to the input parameters, and the balance of the advantages of the current plan is very small.

Page 30, 31, environmental impact:
- The cell contents and drill cuttings scenarios are not assessed critically by DNV-GL.
- DNV-GL stresses the great majority of the footprint that is covered by less than 1 mm of sediments in the environmental impact comparisons; however, the area that is covered by thicker deposits (>10 mm) with a higher PEC/PNEC content has a much larger impact in the dynamic scenario (although the area is small).
- Cost estimates and assessment of safety risks are not independently verified.
- No generally recognized thresholds for acceptable levels of release or persistence of THC or other pollutants.
- The current environmental statement contains a large number of judgements that are at least partly subjective.
- The ES does not consider the human impact of accidents.
- IRG does NOT consider that the current ES provides a fully balanced overview of all relevant outcomes.
- DNV-GL have not challenged the validity of some potentially unreliable data provided to them.

Page 30, 31, 32, long-term issues:
- The following will remain behind:
    - The brent alpha steel jacket.
    - The concrete legs and storage cells (three GBSs).
    - Contaminated sediments, water, and drill cuttings.
    - Several pipelines.
- Shell has agreed to a monitoring program to:
    - Make sure that the degradation proceeds as expected.
    - Assure that there is no additional safety and environmental issues in the future compared to current estimates.
- IRG is satisfied with the environmental surveys for obtaining parameters to establish a baseline, with two major concerns:

    - Ships can (with some limits) approach the platform, so that the nearest sample is 50-100 m from the platform.
    - Drill cuttings under or close to the platforms are not sampled.
- IRG states that it is desirable to have samples closer to the platform to reduce the uncertainties.
- No information on future surveys is given. Some indications in the report is desirable.
- The major concern of the IRG is that if in the future the re-assessment of the safety risks to the users of the sea points to a need for additional corrective actions, there is no guarantee that those activities can be performed considering the degraded structures that might be very unstable.
- There is a need for pipeline span (i.e., an unsupported length of pipe) monitoring and (if needed) guaranteed remediation actions in the future.
- What happens if remediation actions are necessary but Shell and its partners no longer exist?
- *"There is very little details of the monitoring procedures given"*.

Question 6 (Annex)

Notes and highlights from the Brent Decommissioning Derogation Assessment on the topic of uncertainty in general:

Page 80: *"The co-venturers note that the requirement in Annex 2 of OSPAR Decision 98/3 is that uncertainties should be 'taken into account', not that they should all necessarily be quantified. Annex 2 also states that assessments 'shall be based upon conservative assumptions'. The draft Brent Field DP and its supporting TDs and ES acknowledge that there are uncertainties in attempting to quantify outcomes and effects. The co-venturers have addressed uncertainty in two ways; by completing additional modelling and assessments using different assumptions, several of which, particularly those relating to events or effects that might occur far in the future, were deliberately chosen to be conservative, and in the CAs by comparing options using different weighting scenarios."*

Notes and highlights from the IRG report on the topic of uncertainty in general:

Page 2: *"... 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) 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."*

Page 3: *"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 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."

Page 4: *"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. [...]*

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."

Page 34: *"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. [...] 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 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."

Notes and highlights from the Brent Decommissioning Derogation Assessment:

Page 23: *"It is difficult to predict with accuracy how and when these structures will eventually collapse. Studies show that the visible part of the legs could remain in place for 150-250 years. Once parts above sea level have degraded, the section of the legs under the sea could last for another 300-500 years. The oil storage cells might remain largely intact for at least 1,000 years."*

Page 244: *"Anatec used the Atkins study on degradation mechanisms and collapse scenarios as a starting point, acknowledging the caveat that it is difficult to predict with a high degree of confidence exactly how the remains of a GBS may degrade or the sequence and rate of degradation."*

Notes and highlights from the IRG report on uncertainty in timing of collapse of the GBSs:

Page 16: *"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."*

Notes and highlights from the Brent Decommissioning Derogation Assessment on the uncertainty in timing and rate of release of the GBS contents:

Page 289: *"The timing of any potential passive or dynamic release of cell water from each GBS cannot be predicted with certainty"*

Notes and highlights from the IRG report on the uncertainty in timing and rate of release of the GBS contents:

Page 38: *"the evidence supporting leaving the cell contents in place may be considered adequate to support the EIA, but is still uncertain because [...] There is great uncertainty about the timing, mode and rate of eventual release of the cell contents to the environment."*

Notes and highlights from the IRG report on the uncertainty in determining the quantities of contaminated materials.

Page 21: *"The information available on the presence of cuttings in the tri-cells at Brent Bravo and Delta remains incomplete because of sampling difficulties."*

Page 23: *"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."*

Page 38: *"the evidence supporting leaving the cell contents in place may be considered adequate to support the EIA, but is still uncertain because [...] 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."*

Notes and highlights from the Scientia et Sagacitas report on the uncertainty in determining the quantities of contaminated materials:

Page 6: *"[...] obtaining adequate data was nearly impossible to achieve (e.g. cell sampling operations on live producing platforms with pressurised environments) [...] This has resulted in issues, such as applying 'averages' of sample results to engineering works etc., which is inappropriate and results in too many uncertain factors that have not been resolved."*

Page 11: *"The quality of the base data used impacts all subsequent engineering and environmental analysis works throughout the project, as shown in section 1.2.2. The base data made available as a result of sampling operations is very limited in both quantity and quality. [...] Brent Bravo and Brent Charlie Storage Cell inventories are 'assumed' with no factual evidence to support the assumptions. Brent Delta inventories are 'extrapolated' from 3 poor cell sample results across the remaining 13 cells. The Brent Delta results were then further unjustifiably extrapolated across the other CGBS storage Cells on Brent Bravo and Charlie. Even Shell/Exxon indicate this is a concern in their documentation but then appear to ignore the implications."*
"Without a proper assessment of the volumes and nature of the materials inventory in the storage cells it is not possible to identify, with confidence, the necessary works to recover/remove inventories. For example, Interphase material volumes have not been mapped, so there can be no confidence in any estimates of what removal operations will really be required. As such, there are concerns about the use of indicative/assumed data in the CA process, thus introducing significant levels of uncertainty into the process with accompanying bias into scoring exercises and ultimately the 'preferred options'."

Page 14: *"Samples have only been retrieved from the shallow sediment layers. [...] It is highly likely that samples from deeper within the piles will show more signs of contamination with the older hydrocarbon-based drilling fluids/chemicals originally used residing in the lower levels of the cuttings piles."*

Page 28: *"The above ranges in data, and complete lack of physical data for Brent Bravo and Brent Charlie cell contents mean that is it not possible to say with confidence that extrapolating results from mapped cells across the 3 CGBS structures is a fair and valid approach to cell mapping and cell content volume calculations."*

Notes and highlights from the IRG report on the uncertainty in environmental impact of the spreading of contaminated materials:

Page 2: *"... the IRG accepts the evidence that supports the conclusions that [...] 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."*

Page 21: *"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."

Page 28: *"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."*

Page 29: *"The IRG considers the PROTEUS and other modelling results to be indicative only"*

Page 31: *"the IRG considers that the cell content and drill cuttings scenarios modelled and the resulting model outputs could have been examined more critically."*

Page 31: *"The IRG notes that the cost estimates and assessments of safety risks have not been independently verified. [...] 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 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."*

Page 38: *"the evidence supporting leaving the cell contents in place may be considered adequate to support the EIA, but is still uncertain because [...] 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."*

Notes and highlights from the Scientia et Sagacitas report on the uncertainty in environmental impact of the spreading of contaminated materials:

Page 14: *"There is an inability to accurately model future contaminant release environmental impacts as the future condition of the receiving environment cannot be predicted. It is thus not possible to accurately assess the environmental impact of disturbance to establish that the environmental impacts will be minimal. The IRG raised this issue, but it appears to have been ignored by the applicant. Given this situation it is unclear why the 'precautionary principle' is not being applied."*

Notes and highlights from the Brent Decommissioning Derogation Assessment on the uncertainty in determining the safety risks to users of the sea:

Page 244: *"The potential long-term safety risk to other users of the sea was a very important issue for the IRG; the topic and the co-venturers' modelling of the safety risks were discussed on numerous occasions by them, and the co-venturers performed additional modelling on different exposure scenarios. These included so-called 'black swan' events, where an event of very low probability but very high negative consequence, might occur. The IRG strongly made the point that it is not possible accurately to forecast either shipping intensity or commercial fishing activity in the very long-term future. [...] The Anatec study and the fisheries study by Mackay Consultants both acknowledge that it is very difficult to make predictions far into the future about the level and indeed nature of commercial fishing in the area. Similarly, it is difficult to make predictions about commercial shipping; new larger vessels are being introduced, unmanned vessels are being developed, the frequency of shipping movements is changing, and routes near and through the Field may change once nearby oil and gas structures, and the Brent installations, are decommissioned. [...] In Option 1 'Partial removal' the safety risk to other users of the sea comes solely from the snagging risk on the 'stubs' of the partially removed legs. In Option 2 'Leave in place' the risk to other users of the sea comes from two sources:*
1. Ship and fishing vessel collisions while the legs remained above sea level and until they degrade and collapse to a depth at which interactions with the hulls of surface vessels was physically impossible.
2. Fishing gear snagging on the legs after they have degraded below sea level."

Notes and highlights from the IRG report on the uncertainty in determining the safety risks to users of the sea:

Page 17: *"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). [...] 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."*

Page 37: *"[...] 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)."

Notes and highlights from the IRG report on the uncertainty in the Comparative Assessment weighting the pros and cons of "remove" versus "leave-in-place":

Page 10: *"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, 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."*

Page 18: *"The IRG [...] 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."*

Page 33: *"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. [...] 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 [...] Such procedures can rapidly become complex and confusing in any non-trivial case [...] 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."*

Notes and highlights from the Scientia et Sagacitas report on the uncertainty in the Comparative Assessment weighting the pros and cons of "remove" versus "leave-in-place":

Page 7: *"Where poor data exists and is coupled with 'immature' technical studies (AACE Feasibility/Conceptual or Class 5/4 as shown in Fig 2 following) there should be recognition that significant uncertainties will exist. These will produce 'ranges' of costs, schedules, risk levels etc. that should be incorporated into any CA process evaluation."*

Page 30: *"[...] the failure to address uncertainty bands has additional significant Comparative Assessment bias implications and is an additional source of major concern."*

Question 7 (Annex)

Quotes from the reviewed documentation relevant to Question 7:

IRG report: *“The IRG considers that both partial and full removal of Brent Alpha jacket are feasible.”*

IRG report: *“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 report: *“The Framework for the Assessment of Proposals in Annex 2 of OSPAR Decision 98/3 states that the information collated in the assessment shall be ‘sufficiently comprehensive to enable a reasoned judgement on the practicability of each disposal option’, and ‘the conclusion shall be based on scientific principles... ....and linked back to the supporting evidence and arguments’ and that it is demonstrated that ‘there are significant reasons why an alternative disposal....is preferable to reuse or recycling or final disposal on land’. DECC Guidance Notes also state ‘it is unlikely that cost will be accepted as the main driver unless all other matters show no significant difference’.”*
“On the basis of this assessment, the ‘CA-recommended option’ for the Alpha footings alone is Option 3 ‘Leave in Place’. It has a total weighted score of 81.05, in contrast to Option 1’s total weighted score of 75.54 and Option 2’s weighted score of 74.21.” But technical feasibility and cost weigh heavily. Removing technical feasibility and cost are criteria makes option 3 the least recommended option. The sensitivity analysis on page 131 (Shell, 2018) only gives additional weight to one category at the time, or removes economic weighting, in which case “Leave in situ” is the favoured option each time. Besides, differences are small and the results are not binding.

Shell report: *“Consequently, it has been concluded that the sub-criterion ‘cost’ is a strong differentiator between the options for the Alpha footings alone.”*

Shell report: *“Following the assessment of the weighted scores for each sub-criterion, the identification of a CA-recommended option, and then the examination of the real data informing those scores, it has been concluded that in terms of the Alpha footings alone, the significant sub-criteria serving to differentiate the options are ‘technical feasibility’, ‘safety risk to project personnel offshore’ and ‘cost’.”* These are all internal to Shell.

Shell report: *“The Charlie cell-top drill cuttings pile is […] the largest drill cuttings pile in the Brent Field [...] The modelling study indicated that the Charlie cell-top cuttings pile (and thus the combined cell-top and seabed cuttings pile at Charlie) exceeded the oil loss rate threshold in OSPAR Recommendation 2006/5. As required by this Recommendation, a Stage 2 Assessment was therefore undertaken to determine the Best Available Technology (BAT) and/or Best Environmental Practice (BEP) for the management of the Charlie cell-top drill cuttings pile. This assessment concluded that this drill cuttings pile should also be left in situ to degrade naturally.*

… On Charlie, however, the size, shape and location of the drill cuttings pile (which is approximately 11m tall and is protected and supported by the cluster of external conductors) means that even a small-scale disturbance would be likely to destabilise the whole drill cuttings pile. It was therefore concluded that, should any degree of disturbance or displacement be required to allow other decommissioning scopes to proceed, the entire volume of the Charlie cell-top drill cuttings pile should be removed and taken to shore for treatment and disposal."

Shell report: *"if the steel piles on the footings were cut externally, all of the drill cuttings pile would have to be removed [...] the recommended option would be to remove the whole pile by suction dredging and transport the slurry of sea water and cuttings to shore, for treatment and disposal"*

If future regulations require the complete removal of the GBS storage tanks, it is preferred for these tanks to be void of pollutants, favoring their present-day removal. IRG report: *"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."*

Shell report: *"The estimated CO_2 emissions in Option 1, 26,100 tonnes, are approximately 32% less than those of Option 3 (38,500 tonnes). In broad terms, however, both these estimates are approximately an order of magnitude lower than the annual CO_2 emissions from Brent platforms when they were operating…"* 12.000 tonnes CO_2 is a significant amount, even if comparatively low for Shell. Using similar reasoning: the added cost of removing all Brent Alpha materials and wastes is far exceeded by Shell's earnings from Brent oil.

Shell report: *"The other environmental category in which significant impacts were identified was the Energy and Emissions category, which for the three GBSs together amounted to approximately 3.8 million gigajoules (GJ) and 373,000 tonnes of CO_2. For the three GBSs together this was identified as a 'large negative' impact. By far the majority (99 %) of this energy use and emissions to atmosphere would be associated with the theoretical activities that would be undertaken by others to source and manufacture from raw materials the recyclable materials that would left in the sea and not recycled."*

Annex 2: Reviewed documentation

- OSPAR Commission (1998) OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations. Ministerial Meeting of the OSPAR Commission. Sintra: 22-23 July 1998.

- Independent Review Group (2017) Shell Brent Decommissioning Project, Final Report, 3 February 2017.

- Shell U.K. Limited (2017) Brent GBS Contents Decommissioning Technical Document: A supporting document to the Brent Field Decommissioning Programmes. Shell Report Number BDE-F-GBS-BA-5801-00002, February 2017.

- Shell U.K. Limited (2018) Brent Decommissioning Derogation Assessment: An Assessment of Proposals for the Disposal of the Disused Steel and Concrete Substructures of the Brent Field Installations. Shell Report Number BDE-F-GEN-HX-7180-00001, November 2018.

- OPRED: Offshore Petroleum Regulator for Environment and Decommissioning (2019) Consultation on the UK Government's Intention to Issue a Permit under Paragraph 3(a) and 3(b) of OSPAR Decision 98/3 for Leaving In Situ the Footings of the Brent Alpha Steel Jacket and the Brent Bravo, Brent Charlie and Brent Delta Gravity Based Concrete Installations, January 2019.

- Scientia et Sagacitas Ltd. (2019) Review of the Shell/Exxon Brent Decommissioning Derogation Assessment and of the corresponding proposal by UK BEIS, May 2019.

- Correspondence between the United Kingdom and Germany regarding Brent Decommissioning Derogation.

Annex 3: List of acronyms

BEIS	Department for Business, Energy and Industrial Strategy
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CA	Comparative Assessment
DP	Decommissioning Programme
ES	Environmental Statement
GBS	Gravity Based Structure
IMO	International Maritime Organisation
IRG	Independent Review Group
JIP	Joint Industry Project
LAT	Lowest Astronomical Tide
MCDA	Multi-Criterion Decision Analysis
NORM	Naturally Occurring Radioactive Material
OPRED	Offshore Petroleum Regulator for Environment and Decommissioning
OSPAR	Oslo Paris Convention
PAH	Polyaromatic Hydrocarbons
TD	Technical Document
THC	Total Hydrocarbon Concentration
TPH	Total Petroleum Hydrocarbon

Annex 4: Members of the independent evaluation group

Dr. Hamid M. Nick (chairman) has been a research lead and involved in many industrial and research projects related to water quality of deep lakes, sediment contamination, biological processes, enhanced/improved oil recovery, compaction-induced subsidence, constructions, and north sea oil fields production and development.

Dr. Ali A. Eftekhari is experienced in analysing the energy consumption and the environmental footprint of fossil fuel production and processing with a special focus on the CO_2 emissions of oil and gas production, transport, and refineries and the energy requirement of the abatement processes. He also has designed a framework for the analysis of CO_2-free production and consumption of fossil fuels, which is applied to the gasification of European coal resources. He also designed several downstream processes for the petrochemical industries.

Dr. Karen Feilberg has extensive experience in environmental chemistry, chemical risk assessments, and EU environmental legislation. She is an experienced researcher and team leader in the field of oilfield chemistry.

Dr. Dirk van As has studied the natural sciences using physics as a foundation for two decades. He specializes in climate impacts, including the interactions between our planet's atmosphere, oceans, cryosphere and biosphere.