Guidance document for characterization of offshore drill cuttings piles

Version 4, 21 October 2016

PREFACE

On behalf of the Norwegian Oil Industry Association (OLF – now the Norwegian Oil and Gas Association), the Norwegian Institute for Water Research (Niva) and the Norwegian Geotechnical Institute (NGI) developed the first version of *A guidance document for physical, chemical and biological characterisation of offshore drill cuttings piles* in October 1999. The OLF issued version 2 of this document in 2000, with version 3 issued in 2003 under the coordination of the OLF and in alignment with the ongoing UKOOA drill cuttings management initiative. The guidance document has been applied in the OSPAR area, and particularly in UK and Norwegian waters.

Significant developments have occurred in the management of drill cuttings piles since 2003, particularly in relation to the OSPAR recommendation of 2006/5 and to a number of field surveys and research initiatives which have increased knowledge about these piles.

Norwegian Oil and Gas therefore initiated a project in 2016 to update the 2003 version to reflect current knowledge and best practice. DNV GL has been responsible for editing the guidance with input and contributions from operating companies which have experience of the subject.

Stavanger, 21 October 2016

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SUMMARY

Based on the UKOOA research programme on drill cuttings, modelling fate and persistence, and national reporting on the drill cuttings piles, OSPAR stated in 2009 that management of drill cuttings piles should form part of the decommissioning plan for an installation. The conclusion was that all piles were likely to fall within the OSPAR thresholds (less than 10 tonnes of oil leaching to the water per annum and persistence of less than 500 km^2/y). Allowing the cuttings piles to degrade naturally *in situ* was considered to be the BAT/BEP.

Management options for drill cuttings piles should be addressed in the decommissioning plan for a field. Knowledge about the characteristics of such piles is therefore required to evaluate environmental impacts from cuttings pile disposal options, for example, and to prepare the removal of installations.

More recent investigations of cuttings piles have focused on chemical analyses of shallow corer samples from these. Some piles have been mapped or modelled to confirm that they fall within the OSPAR limits. Before sampling, the distribution/topography (bathymetry) of the piles should be mapped to provide input for appropriate sampling programme design.

Using ROV-operated push corers is recommended for collecting samples 20-50 cm long from five to 10 locations for a small to medium-sized pile. The number of sampling locations should be adjusted in line with the size of the pile and the purpose of the survey. Corer samples should be sectioned and analysed for standard parameters (such as THC, PAH, metals, grain size and TOC) in accordance with offshore environmental monitoring guidelines (such as M-300/408 NEA 2015). Contaminants in the upper centimetres may influence the environmental condition of the seabed and the ambient water.

Deep coring and sampling, and the description of the macrofaunal community on a cuttings pile, are recommended as optional extras.

GLOSSARY

APE	Alkylphenolethoxylates
AUV	Autonomous underwater vehicle
BAT	Best available techniques
BEP	Best environmental practice
BHQ	Benthic habitat quality
BTEX	Benzene, toluene, ethylbenzene, o, p, m-xylenes
DECC	Department of Energy and Climate Change (became part of Department for Business, Energy & Industrial Strategy in July 2016)
DP	Decommissioning plan (Norway), decommissioning programme (UK)
Drill cuttings	Fragments of rock drilled from the formations down to the reservoir. Contain remnants of drilling fluids. May create piles on the seabed after discharge.
EIA	Environmental impact assessment
ES	Environmental statement
GBS	Gravity-based structure
Hazid	Hazard identification
IOGP	International Association of Oil and Gas Producers (previously OGP)
JIP	Joint industry project
LSA	Low specific activity (in this context, radiation in scale/rock from reservoir)
LSC	Limit of significant contamination
NCS	Norwegian continental shelf
NEA	Norwegian Environment Agency
NORM	Naturally occurring radioactive material (radioactivity of natural origin)
NPD	Napthalenes, phenanthrenes and dibenzothiofenes
OBM	Oil-based mud (oil-based drilling fluid)
OGP	former abbreviation for IOGP, qv
OGUK	Oil & Gas UK
OIC	Offshore Industry Committee
OLF	former name of the Norwegian Oil and Gas Association
PAH	Polycyclic aromatic hydrocarbons
PBM	Pseudo oil-based mud (esters, olefins, etc)
PCB	Polychlorinated biphenyls
PDO	Plan for development and operation
PFC	Perfluorinated compounds (can be a component of firefighting foams)
PPE	Personal protective equipment
ROV	Remotely operated vehicle
SPI	Sediment profiling images
TBT	Tributyltin
THC	Total hydrocarbons (in this context C_{n12}–C_{n35})
TOC	Total organic carbon
TOM	Total organic material
UKCS	UK continental shelf
UKOOA	UK Offshore Operators Association
WBM	Water-based mud

1 INTRODUCTION

1.1 Background

Drill cuttings originate from the drilling process as the bit advances through the bedrock, with drilling fluid carrying rock fragments back up to the rig. Various types of drilling fluids have been used and discharged over past decades. The environmental impact of such discharges, especially those involving oily cuttings, has led to stricter regulation which has reduced and gradually eliminated the harmful effects. In particular, the ban on discharging oily cuttings (with more than one per cent oil) in 1991 (1993) has greatly reduced the footprint of cuttings on the seabed.

However, piles of cuttings with unique chemical content and varying volume have accumulated beneath and adjacent to a number of offshore petroleum installations. Such deposits may represent a management issue when planning field decommissioning and call in some cases for the cuttings to be moved away in order to cut piles (steel jacket foundation) below seabed and carry out safe lifts when removing obsolete facilities. Different management options exist for dealing with cuttings piles, depending on their character: size, content and environmental risk.

The Norwegian Oil and Gas Association has developed a guidance document for characterisation of drill cuttings piles. The first version was issued in 1999, with the most recent version published in 2003. This document was developed in close collaboration with the UKOOA drill cuttings initiative and has been applied on the UKCS and the NCS.

Several surveys of offshore drill cuttings piles have been conducted since 2003. Sampling techniques have therefore improved and more has been learnt about the status and development of the piles. That knowledge and experience make an update of this document timely.

In addition, a framework for management of drill cuttings piles was issued by OSPAR in 2006 (OSPAR 2006/5). This was largely based on findings from the UKOOA drill cuttings initiative in 1999-2005 period. OSPAR 2006/5 referenced the 2003 version of the Norwegian Oil and Gas guidance document.

The OSPAR recommendation on drill cuttings management specifies criteria for oil leakage to the water column and pile persistence. These threshold values should be taken into account when managing drill cuttings piles during field decommissioning.

1.2 Purpose

This guidance document will contribute to the process of planning sound management of drill cuttings piles as part of overall decommissioning planning.

It will specifically recommend an approach to characterising drill cuttings piles as input to this process. It focuses on field sampling methods as well as strategy and laboratory analyses. Regular environmental monitoring of offshore fields mainly covers the area greater than 250m (100m at a few stations/fields) from the facilities. Generally speaking, however, the cuttings piles and their main contamination are located within 250m of the platforms and specific surveys are required.

This guidance document should help the operator describe:

- the position of the pile
- pile volume
- pile area/topography

- the chemical content of the pile (THC, PAH, metals).

Optional measurements

- physical characteristics (cone penetration tests, density, shear strength)
- characterisation of the benthic community.

The guidance document should also help the operator to evaluate a cuttings pile against the following criteria set by OSPAR recommendation 2006/5:

- the leaching rate of oil
- persistence of the contaminated area.

Determining whether a pile ought to be investigated should be based on the field's drilling discharge history, with regard both to the quality and quantity of the released substances and to recent seabed environmental monitoring results.

Characterising a cuttings pile or seabed contamination in its vicinity may also be required for operational purposes (such as dredging or installation of new facilities) or as input to permit applications for dealing with the cuttings.

1.3 Assumptions

This guidance document is based on knowledge gained through the UKOOA R&D JIP on drill cuttings (UKOOA 2002, 2005) and later sampling and evaluations of a variety of drill cuttings piles. Attention is concentrated on old piles with residues of oil-based mud. While techniques for characterising cuttings piles are similar regardless of pile content, the scale of the survey and analyses may be smaller for piles which originate from drilling with other fluids.

This guidance document recommends a level of sampling and analysis parameters. However, operators or licensees are responsible for determining the magnitude of the work and the resources to be utilised, and for establishing a detailed plan to characterise cuttings piles. They should also take further field decommissioning activities into account, including an evaluation of alternatives for disposing of cuttings piles and field installations (figure 2-2).

1.4 Environmental effects of drill cuttings piles

Synthetic muds are based on olefins, ethers or esters, and generally degradable naturally much more readily than OBMs. However, such degradation may result in local oxygen depletion. Biological effects in areas where such muds have been discharged are generally smaller than with OBMs but greater than for WBMs.

Cuttings piles accumulated from drilling with WBMs generally do not pose a potential for significant environmental effects (IOGP 2016, Bakke et al 2013). Their toxicity is low compared with OBM, but particle sedimentation can have a local influence on marine life. The size of drill cuttings accumulations will also need to be evaluated in decommissioning planning. Cuttings piles derived from WBM therefore have a smaller environmental impact, but can be surveyed using an approach similar to that described in this document.

This document does not seek to describe the fate and impact of drill cuttings discharges. Generally speaking, oil contamination in the sediments and effects on benthic fauna were significantly reduced when discharges of oil-based drilling fluids became more strictly regulated in 1991-93 and in practice ceased.

Several fairly recent documents address the effects of drilling fluids and cuttings discharges on the marine environment (such as Bakke et al 2013, Research Council of Norway, 2012, IOGP 2016, OSPAR 2009a and DNV 2013a).

Cuttings material has been dredged at a number of locations and information has been collected about possible methods and challenges as well as environmental impacts.

1.5 OSPAR recommendation and screening of cuttings piles

OSPAR recommendation 2006/5 (OSPAR 2006) on a management regime for offshore cuttings piles states that piles with an oil loss to the water column of less than 10 tonnes per annum and a persistence seabed area smaller than 500km²yrs [1] may be left *in situ* to degrade naturally. If a pile does not fulfil these requirements, comparative assessment should be initiated for further evaluation of environmental effects and possible disposal options (figure 1-1). This stage 2 investigation calls for a BAT and/or BEP assessment. OSPAR required the initial screening to be reported in 2008. This should be based on the Norwegian Oil and Gas guideline document or equivalent.

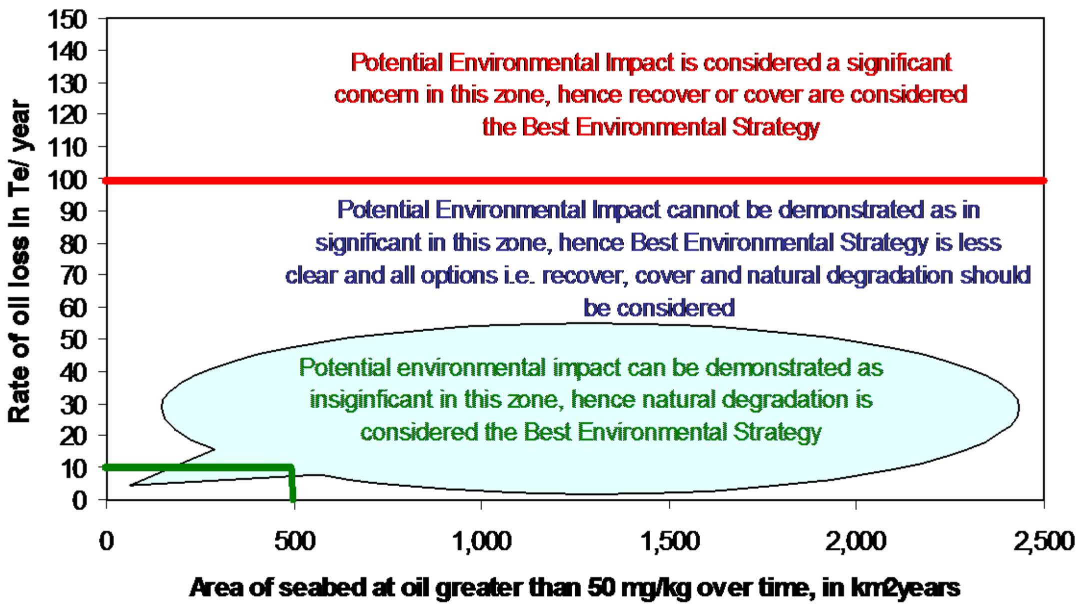

Figure 1-1. Criteria for environmental significance (UKOOA 2002 and OSPAR 2006).

The OLF (now Norwegian Oil and Gas) reported on the status of 120 Norwegian drill cuttings piles in relation to the OSPAR criteria in 2008 (DNV 2008). Based on the available data, all the piles were assessed to be within the OSPAR limits on oil loss and persistence. Conclusions from this initial screening were mainly based on measurements of THC in the sediment and the piles, the changes (reduction) in the contaminated area over time, and expected future developments. In addition, the loss of oil was evaluated on the basis of available experimental data and drill cuttings reports, but no exact figures were reported.

Similarly, UK Oil & Gas reported on 174 piles (or 168 depending on the definition used) in 2008 after a screening (ERT 2008). This concluded that all the piles were within the OSPAR limits. That was based on the persistence of the contaminated area (either measured in the field or modelled/extrapolated from the number of wells drilled) and a conversion factor derived from modelling work during the UKOOA JIP on drill cuttings.

[1] A persistence of 500km²yrs could mean an area of one km² is contaminated for 500 years or an area of 500km² is contaminated for one year. A concentration of 50mg THC/kg dry sediment is set as the limit for pollutant/presence of drill cuttings.

In addition to those mentioned above, several more detailed studies of drill cuttings piles in relation to the OSPAR criteria have been carried out. Modelling the oil loss and the fate of the piles has been important for several of these studies, and this work started during the UKOOA JIP on drill cuttings piles. The main findings from this project were reported in 2005 (UKOOA 2005).

Reporting on the cuttings piles in the North Sea area represented the initial screening of oil-contaminated piles as requested by OSPAR. OSPAR issued an implementation report on recommendation 2006/05 in 2009 (OSPAR 2009b). This accepted that the cuttings piles were within the limits and could be left *in situ* for natural degradation. Further management of drill cuttings piles should form part of decommissioning plans for the installations.

In general, industry practice has been to sample the cuttings pile as part of planning for removing offshore facilities. The results of characterisation, assessment of management options for cuttings piles and associated environmental impacts have been presented in the ES/EIA for decommissioning the installation/field.

Furthermore, management of cuttings piles is important as part of planning for disposing of facilities (such as jackets), related either to their removal or to leaving the footings in place pending OSPAR derogation. Characterising the cuttings piles is therefore also important in preparing applications and obtaining permits for some subsea activities such as dredging.

2 DECOMMISSIONING PLANNING

2.1 Preparing a decommissioning plan

In North Sea countries with offshore petroleum activities, field decommissioning and disposal are regulated in accordance with OSPAR decision 98/3. Installations with steel substructures below 10 000 tonnes should be removed after production from the field ceases, while larger substructures installed before February 1999 may be left *in situ* subject to OSPAR derogation. Although the regulatory process varies somewhat between countries, a decommissioning plan may be considered similar in its content and purpose. It will reflect the process of evaluating and documenting disposal alternatives and recommend a solution.

As mentioned above, a conflict will arise in many cases between the BAT strategy to leave the cuttings pile undisturbed for natural degradation and the removal of installations in accordance with OSPAR decision 98/3. The latter may require the contaminated material to be removed in order to secure access, for example, to cut piles (steel jacket foundation) below the seabed surface, to relocate drill cuttings for performing safe lifts or to remove the conductor frame. The quantity of cuttings material and the contamination status of the pile are important data ahead of dredging activity. Such information is required as part of the permit application and to plan measures to mitigate the potential for negative environmental effects from disposal activities.

The stage in the field life cycle where the current guidelines apply is presented in figures 2-1 and 2-2. The evaluation of disposal options for the cuttings piles will form part of the EIA process related to decommissioning planning. Where Norway is concerned, the OLF handbook on EIA gives further guidance on this process (OLF 2001), while the DECC guidance note for decommissioning (DECC 2011) and decommissioning programme templates (DECC 2015ab) provide details for the UK.

2.2 Planning the management of drill cuttings piles

The UKOOA R&D JIP (UKOOA 2002 and 2005) concluded that hydrocarbons are the prime contaminant in drill cuttings piles and the decisive management factor for most piles. Environmental significance will thereby depend by and large on the level of hydrocarbon contamination, on how far this leaches to the surrounding environment and on its persistence. The characterisation survey should provide information relevant for determining management and disposal options for drill cuttings piles. Based on these findings, the condition of the pile with regard to the OSPAR criteria should be evaluated.

This guidance document has been developed to ensure that information is acquired to an extent and at a level of detail which make it possible to evaluate the environmental risk associated with drill cuttings residues at a site. The document is designed to enable documentation of the present position and to determine whether relevant repetitive sampling provides indications about degradation/erosion and time trends. Based on such information, those responsible for the field should be in a position to establish a plan for sound cuttings pile management as an integral part of overall decommissioning planning (see figures 2-1 and 2-2).

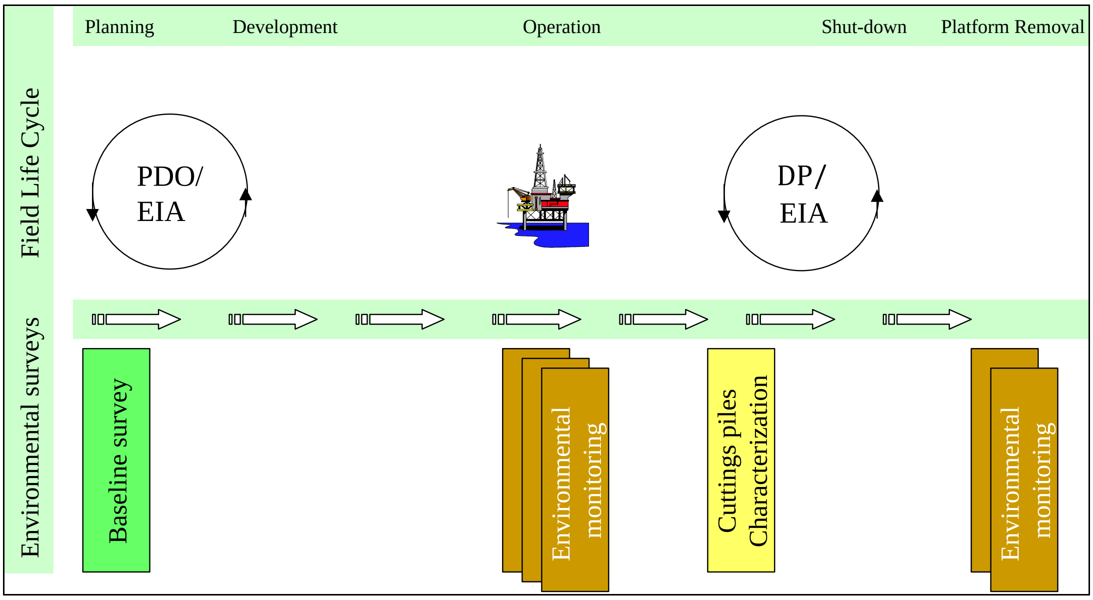

Figure 2-1. Characterisation of cuttings piles in the field life cycle process and in relation to other relevant environmental surveying.

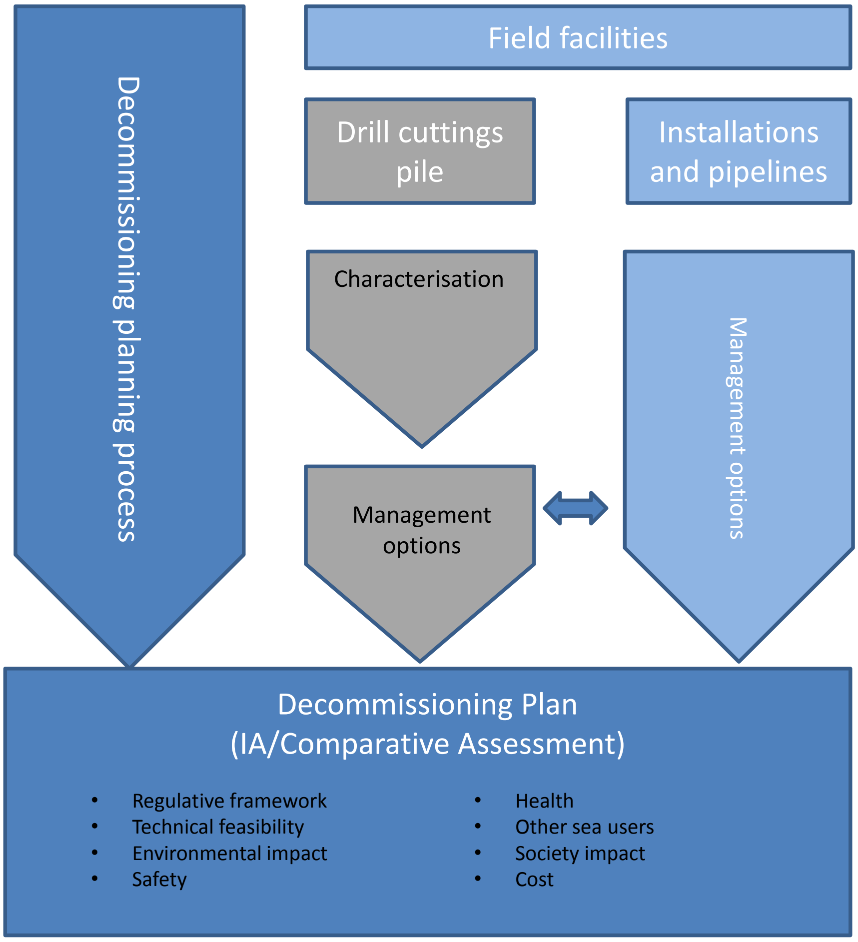

Figure 2-2. The cuttings pile management process as part of developing the overall decommissioning plan.

3 MAPPING THE CUTTINGS PILE VOLUME AND AREA

It is important to know the position, shape, size and volume of a cuttings pile before conducting a more detailed characterisation.

Significant strides have been made over the years in developing the technology for mapping a pile's shape and size, and the instruments and modelling available today generate data of high quality and with a high resolution.

Several instruments can be utilised to map cuttings piles, such as:

- side-scan sonar, multibeam echosounders and sub-bottom profilers
- Digiquartz depth sensors
- video-based mapping.

This instrumentation is usually fitted on a ROV, but may also be utilised from a surface vessel, a platform or an AUV.

Acoustic instruments and/or visual surveys may also identify buried items, visible obstacles or debris which could create problems during sampling and/or disposal of cuttings material.

The surface of a cuttings pile and the adjacent seabed often look similar. In addition, the cuttings may be covered with natural sediment as a result of water-driven particle transport. So performing a visual inspection alone without corresponding sampling is not recommended.

An estimate of cuttings pile area and volume is useful for further assessment of management options, costs and so forth. Some uncertainty will attach to such estimates, particularly with regard to the spatial extension of the pile. It is suggested that the boundary of the pile be set where the water depth is 0.1m lower than the natural seabed in the vicinity or than a baseline measurement. Should such a method be unfeasible because the amount of cuttings material is small, the pile area should be defined on the basis of best judgment and verified by seabed sampling in the next stage. Pile volume is calculated using common software tools based on topographical mapping of its area.

Experience shows that defining the native seabed level can be challenging, since it will vary around the facility. The mapping survey should therefore document in detail how the zero level is measured/defined so that repetitive studies can be conducted over time. Significant differences in volume estimates may exist between successive surveys if the seabed (zero) level or the measuring techniques vary over time. The same method/zero level must therefore be utilised in order to compare survey results over time (such as degradation/erosion of a pile).

Alternatively, structures on the installations (such as mud braces on jackets) can be used to determine the zero level and define the boundary between cuttings and native seabed. These can also be used to calibrate tidal variations in water-depth measurements.

The name and version of the software used to calculate area and volume should be specified, together with a description of how the zero level has been defined.

An assessment of variances in the limits described above in order to assess the uncertainty of volumes is also recommended, since small variances in depth have a large impact on pile volume. In other words, volume estimates should be done with ± 0.2m of variance, for example, in the zero level of the pile.

Should the pile be topped by a significant layer of blue mussels, the volume of this material should be estimated separately from the cuttings. To be able to do this, the thickness and distribution of the mussel bed should be measured by visual inspection (in others words, moving the mussels away at several locations to find the cuttings below) or by using instrumentation.

Some examples of topography plots are presented in figure 3-1.

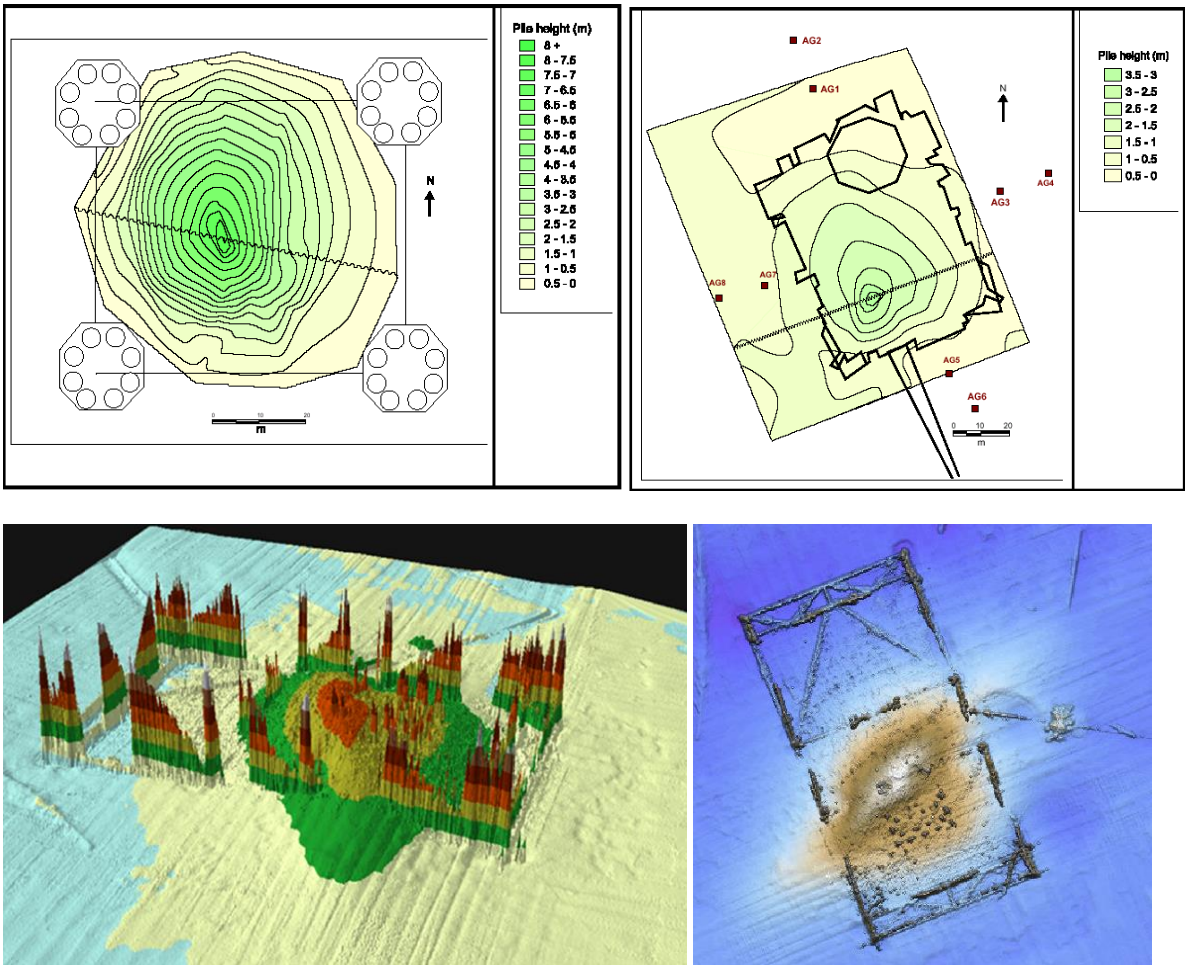

Figure 3-1. Examples of topography/contour mapping plots for cuttings piles (images from RF 2000 and DNV 2013b).

4 RECOMMENDED FIELD SAMPLING STRATEGY AND METHOD

This section discusses the sampling strategy and looks briefly at sampling methods and analyses. Various optional sampling techniques and analytical work are described in more detail in section 6 and in appendices A and B.

4.1 General considerations

The location of a cuttings pile relative to the platform/structure will vary with the type of installation, such as a subsea structure, a steel jacket or a GBS, and the position and height of the discharge pipe above the seabed. Where a subsea installation and a jacket are concerned, the cuttings pile will be located within its footprint and to its side, most probably extending out in the direction of the prevailing current. With a GBS, the cuttings will accumulate on the side of the platform base where they have been dropped. Some of the cuttings can be found atop the domed GBS storage cells and even between them if this space was available.

The sampling strategy described here assumes that access for sampling the cuttings located within the footprint of a steel structure/jacket is limited. For practical purposes, therefore, the same approach is used when planning a sampling survey of drill cuttings piles at all types of structures. However, the sampling plan should be adapted to local requirements specified in each case.

Subsea installations such as pipelines, cables and jacket members can restrict the area available for sampling. The distance to the facility/topside can also limit the scope for deploying crane-operated equipment. Such considerations must therefore be taken into account when establishing and implementing the sampling programme.

Drill cuttings piles are generally very heterogeneous in both horizontal and vertical dimensions with regard to chemical, physical and biological parameters. That makes both survey design and interpretation of the results challenging.

A considerable layer of blue mussels (mostly dead but some alive) may be located on top of a cuttings pile (figure 4-1). They originate from the top/splash zone of the facility and fall from there to the seabed. Such a mussel bed can make it difficult to collect cuttings samples because they fill or block the sampling tubes. In such cases, the mussels can be carefully moved aside before sampling.

Using ROV-operated seabed sampling systems has become very common. With an ROV often part of the standard support vessel spread, such sampling is cost-efficient, safe and easily controlled by good positioning accuracy and video recording. However, some limitations exist with regard to the area collected per sample (in other words, the volume of sample material) and penetration depth for regular equipment.

4.2 The sampling strategy design

The sampling design should be based on the topography of the pile (see the description in section 3). Where piles have a discharge history indicating some potential environmentally harmful content (such as OBM-contaminated cuttings), a field sampling survey should be undertaken.

The main objective when sampling a drill cuttings pile is to obtain surface sediment samples from the upper 20-50cm of the deposit. Contaminants in the top centimetres are exposed to the ambient water and influence environmental conditions. If the samples cover the main part of the cuttings pile, they will also represent the main volume of the pile (assuming this to be relatively flat). Short corers can be deployed to some extent at the edge of the pile to identify historical discharges from the first wells (which also should be present in the core of the pile).

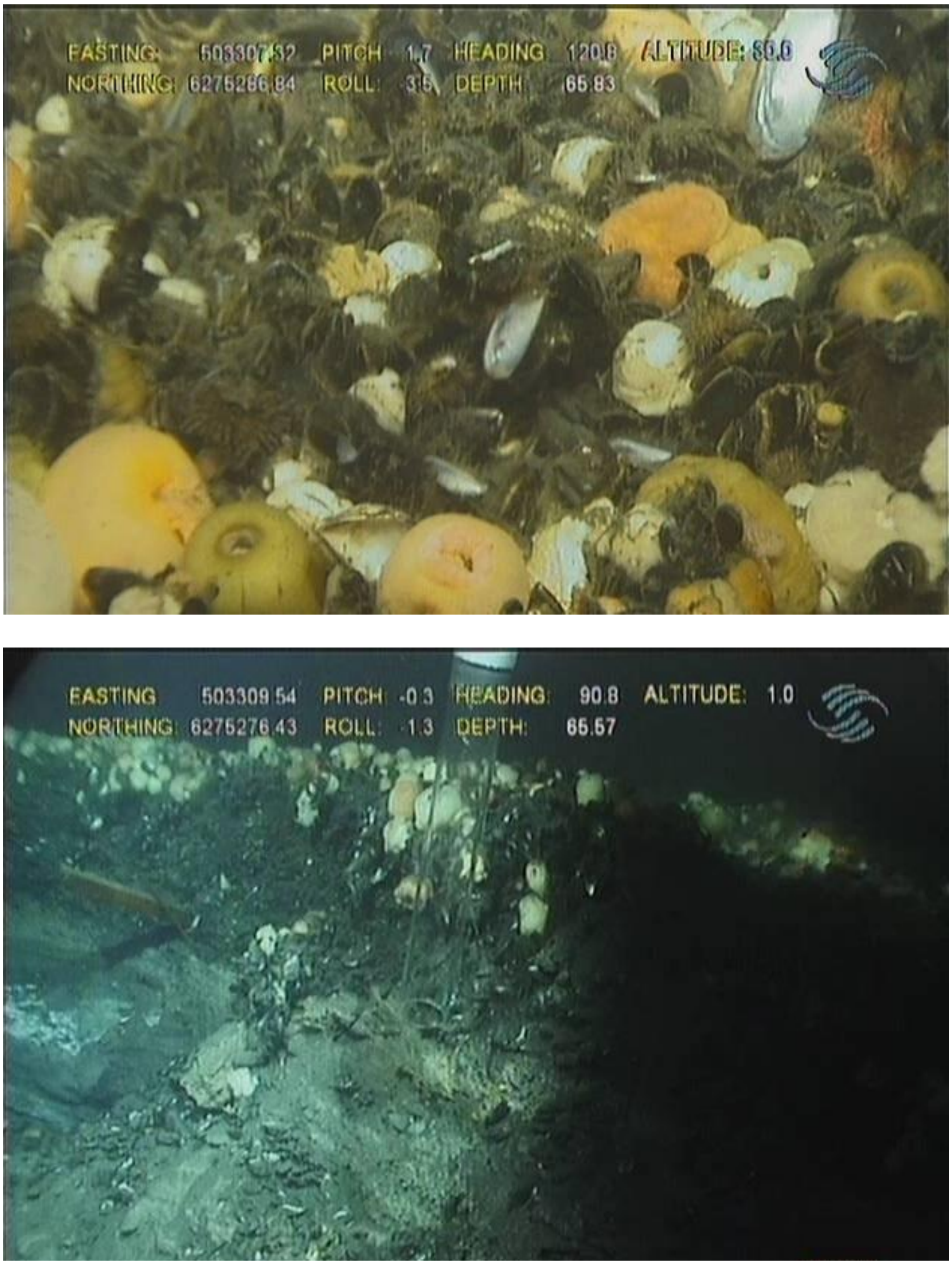

Figure 4-1. Photos of drill cuttings surfaces (mussel bed and anthozoan*s* in the top image) and vertical zonation layers can be identified when part of the cuttings has been dredged (from DNV 2010).

The sampling locations should cover the obvious pile area and the borders where the native seabed dominates. Piles often have an elliptical shape owing to water currents. The sampling locations should preferably be aligned along the main current direction on the seabed, with some stations perpendicular to this (figure 4-2). A sample position grid design or along transects may be useful to cover the pile, but five to 10 samples obviously do not permit a detailed study of all parts of a pile.

Results from point sampling and analysis of the pile for physical, chemical and (optional) biological characteristics will be used to define the limits of contaminated areas and possible boundaries for effects on the macrofauna. Attention should therefore be concentrated on the expected transition zone between the pile and the adjacent seabed to allow for additional sampling of this area.

Sampling of the cuttings within a jacket footprint may be restricted owing to the enhanced risks for ROV and facility. Good advance planning and risk assessments make it more likely that sampling will be successful in this area. If the pile within the jacket is inaccessible, some of the stations outside the footings should contain representative cuttings.

The number of stations should be expanded with increasing pile size, see table 4-1. More cores should be collected and archived for later analyses if more information is requested. Establishing sampling station positions should be based on a review of historical discharge data, information from geophysical surveys of the cuttings pile (topography) and accessibility for sampling.

Table 4-1. Suggested number of sampling stations for cuttings piles.

No of samples	Volume (m^3) and/or area (m^2)		
	< 5 000	5 000-20 000	>20 000
Surface core samples (0-50cm)	5-10	10-20	> 20
Optional sampling			
Deep penetration samples (0-Xm)	2	2-5	2-5
Faunal samples*	2-5	2-5	> 5

* van Veen grab or equivalent, 0.1m^2, five replications per station.

Replicated sampling at the same location is not considered necessary when the aim is to map the horizontal and vertical composition and structure of the pile for management purposes (two replicates may be necessary to collect sufficient material for analysing sections). Planning for more sampling locations in order to improve spatial resolution would therefore be preferable to performing repeated sampling at the same station.

The cuttings pile should be analysed for different layers in order to gain a better understanding of the vertical distribution and variability of contaminants within it. This is obtained by sectioning the corer samples. Splitting the corers at fixed intervals (such as 0-5, 5-10 or 10-15cm) is recommended, since a sample volume of this size permits several analytical methods to be conducted from the same sample (horizon).

Alternatively, the corers can be sectioned in accordance with regular environmental monitoring (such as 0-1, 1-3 or 3-6cm for Norway: OSPAR 2004) or by looking at the visual appearance of and variable layers in the samples. This option makes the top section (0-1cm) directly comparable with regular monitoring samples. Unfortunately, the limited area covered by a corer makes the sample volume small. Multiple samples at a location can be pooled to increase the sample volume.

By analysing selected sections (such as the top, middle or bottom horizons) from the corers alone, the number of samples to be analysed will be reduced compared with analysing all 5cm-long sections of a corer (such as eight samples from a 40cm-long sample). That will save some costs.

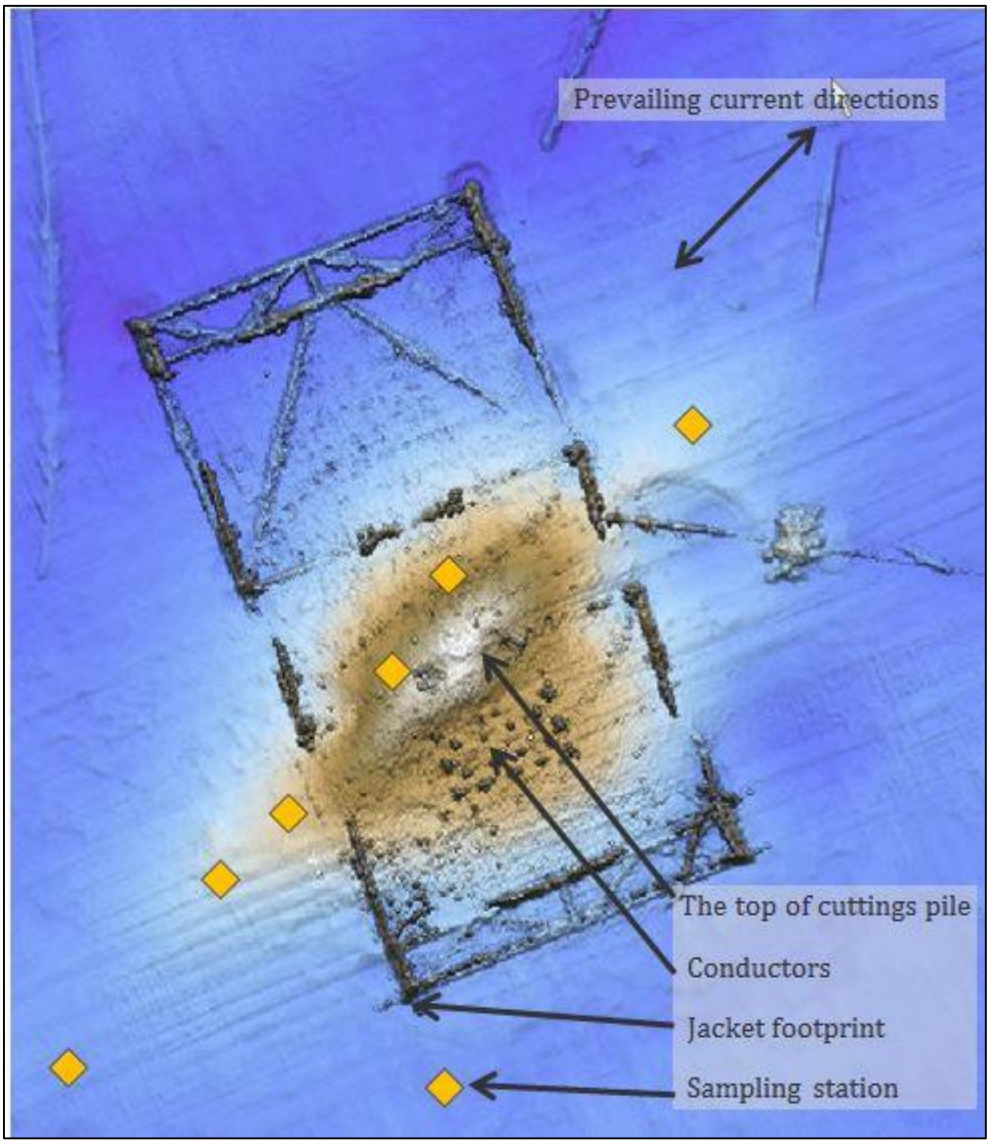

Figure 4-2. Illustration of suggested sampling positions on a cuttings pile where sampling inside the jacket footprint is permitted.

4.3 Sampling at cuttings piles with ROV-operated corers

The use of ROV-operated coring devices (push corers) is recommended for sampling cuttings piles. These techniques have proved very efficient and popular because they permit controlled sampling with regard to seabed conditions, buried infrastructure and personnel (fewer crane lifts). The corers should be temporarily stored subsea in a sample basket to reduce sampling time, and recovered to the surface when all the corers have been used (figure 4-3).

To obtain a sufficient sample volume from each layer/subsample, the inner diameter of the coring tube should be a minimum of 5cm, but 7-10cm is recommended.

The corer should be fitted with a valve at the top which releases water during penetration of the seabed and seals the top to generate a vacuum during retrieval of the sample from the seabed. This is essential for sample recovery.

Generally speaking, the use of a core catcher/tulip is not recommended, since it increases sample compression and creates friction when the sample enters the tube. It also potentially disturbs the layers in the core. In addition, most of the cuttings material is sticky and stays reasonably well in the sampling tubes. A core catcher therefore generates more work with the samples and is not required in most cases. With sandy/coarse sediments, a core catcher can prevent the sample dropping out but reduces the penetration depth.

Sampling sandy sediments with coring devices can be challenging. Patience and gentle twisting of the tube into the seabed can improve the success rate. A subsea system for easy and rapid storage of the sample is also beneficial.

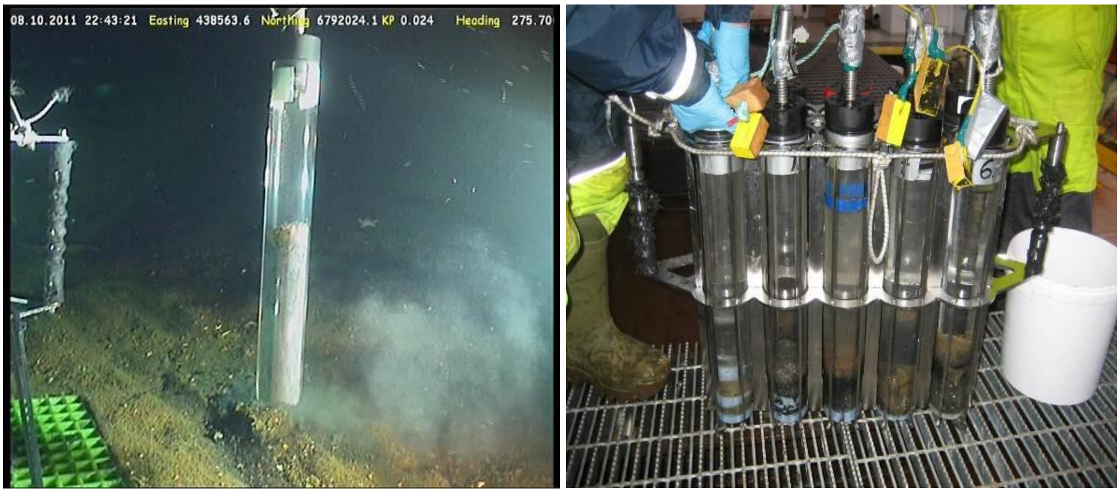

Figure 4-3. A sample corer and corer rack for storing several tubes (DNV 2012).

The use of sampling tools other than ROV-operated push corers can be acceptable if these techniques fulfil the scope of the survey. Sectioning of acquired material into sub-samples and analyses should be similar to coring samples.

ROV-operated corers have limitations in terms of penetration depth into the pile and the surface area covered. Other, optional techniques should therefore be utilised for deeper coring (see chapter 6 or appendix A).

As a minimum, all samples should be documented with photographs and described in terms of length, odour and colour (figure 4-4). The various layers in the core samples should also be measured and described in the field log.

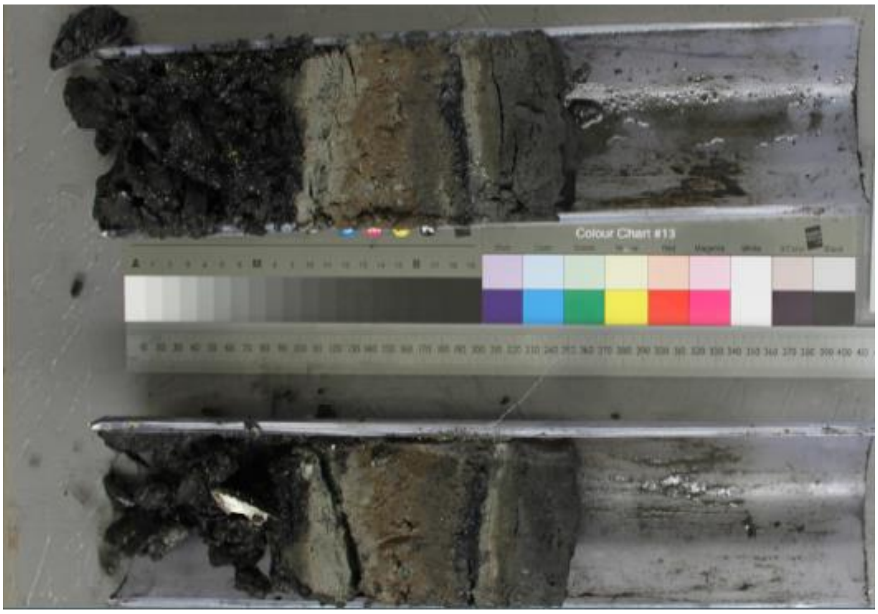

Figure 4-4. A photo of a divided corer with various layers of cuttings and blue mussels, a ruler and a colour coding chart (Gardline 2013).

4.4 Safety, occupational health and environmental issues

Operational hazards presented by using equipment and lifting operations should be addressed before the survey and mitigated through training, procedures, Hazids and safe job analyses. As a general rule, the vessel contractor/operator's routines should be observed.

The cuttings samples may smell of H_2S or oil (diesel and aromatic compounds) and may contain hazardous chemicals which require the use of proper PPE. Gloves, coveralls or rainwear and boots should therefore be worn. In most cases, good ventilation of the work area will be the best solution for reducing risk from gases, but gas masks (or a fresh air hose breathing apparatus) may be used if needed. Gas metering of the H_2S concentration is recommended.

Based on current knowledge, no LSA levels in drill cuttings from the seabed have been documented which pose any risk to personnel involved in sampling. A cuttings pile is composed of rock fragments and is not comparable with scale deposited in pipelines and process systems. Using a field instrument to check radiation from some samples at a site may be useful to ensure that levels are within recommended limits, but this is not a requirement.

Cuttings which have been collected but not bagged for analyses should be disposed of in a container or equivalent rather than being returned to the sea. While such a small volume of cuttings poses no significant hazard to the environment, any discharge should be avoided on principle. Minor amounts of solids and some wash water may be flushed back to the sea, but the remnants of cuttings and wash water should preferably be routed into a drain (typically in the ROV hangar area) and to a slop tank.

So far, sampling of (contaminated) seabed sediments or drill cuttings off Norway has not been regulated or subject to application and permit routines by the NEA.

5 ANALYSIS AND QUALITY ASSURANCE OF CUTTINGS PILE SAMPLES

5.1 Guidelines and standards

Environmental surveys of seabed areas surrounding a cuttings pile are covered in principle by other guidelines (such as OSPAR 2004 or, where Norway is concerned, the activities regulations). Cuttings pile surveys should be coordinated with existing seabed monitoring programmes in a way which ensures comparability between analysis results. When the analytical parameters proposed for the cuttings piles are the same as those used in environmental monitoring, the analytical methods will thereby be harmonised as far as possible between the two sets of guidance documents. Similar harmonisation should be sought when applying this guidance document in other countries.

Where Norway is concerned, reference is made to the NEA guidelines for offshore environmental monitoring (NEA 2015) for details about sample handling, analysis and quality assurance. These guidelines are also relevant for other geographical areas, and are generally in line with OSPAR 2004. The OGP 2012 report describes the general requirements related to suggested procedures for offshore environmental monitoring. Some possible analyses particularly relevant for drill cuttings are listed in appendix B.

Consultants hired for a cuttings pile survey should document that they are accredited or in other ways certified for quality assurance (in other words, in accordance with ISO 14001, BS/EN/ISO 9001:2000 (BSI 2008) principles and ISO/IEC 17025 or equivalents) for the specific field work, analytical services or other tasks requested. In some instances, this is already taken care of by the operator’s prequalification requirements for selecting suppliers. Relevant examples of quality assurance guidance documents for environmental surveys are provided by ISO 5667-19:2004, ISO 16665, OSPAR 2002-16, OSPAR 2004-11 and NEA 2015. The consultants should also document that they can mobilise the full resources required for the survey, including satisfactory backup of equipment and personnel.

5.2 Chemical and physical parameters for analysis

As a general rule, all the samples should as a minimum be analysed with regard to:

- THC and PAH*
- metals (As, Ba, Cd, Cr, Cu, Pb, Ti, Zn and Hg).
- TOC and grain size.

The TOC and grain size distributions are basic parameters which influence the level of contaminants in the sediment and should therefore be included.

Based on discharge history and other possible contaminant sources, selected samples can <u>optionally</u> be analysed for:

Contaminants:
- NPD*
- phenols (APEs)
- BTEX
- esters
- esters
- olefins

Physical parameters:
- density
- water content
- shear strength

Tests or studies:**
- leaching tests
- toxicity tests
- mesocosm study

*Analyses of PAHs and NPDs should be included for some selected samples or, preferably, for all. These substances can indicate the origin and potential toxicity of the hydrocarbons.

** Experiments should generate input for evaluating the potential environmental impact of the cuttings and the OSPAR threshold (loss of oil). Based on current knowledge, however, no finally accepted method generates a very good estimate for oil leaching rates from cuttings piles. An OGUK 2013 review of hydrocarbon leaching tests identified available and prospective techniques (OGUK 2013a). Based on available knowledge in 2008, both the UK and Norway reported that cuttings piles would lose less than 10 tonnes of oil per annum.

Discharges of drilling fluids and cuttings should not result in any significant contamination by PCB, TBT, PFCs and LSA in a cuttings pile. These compounds should therefore only be analysed in surveys with specific requirements.

The heterogeneity found in cuttings makes interpretation of the analytical data challenging. Selecting representative sample data (from the pile as against at the border, for example) and calculating average or median values can be useful in obtaining a figure for the general condition. The low-high values from the analyses should also be presented.

THC is used as the key parameter for biological effects from cuttings piles, and 50mg THC/kg in sediments has been suggested as the concentration where biological effects can be expected (UKOOA 2002, RF 2004, M-300 NEA 2015). This limit was adopted by OSPAR in its recommendation on drill cuttings pile management, and the THC level should be assessed with regard to this concentration.

Region-specific background levels (LSC) are calculated for the NCS on the basis of the regular environmental monitoring surveys. In addition to other established background levels and OSPAR 2005, these concentrations can be used to evaluate the magnitude of pollutants in the cuttings pile.

6 OPTIONAL AND ALTERNATIVE SAMPLING METHODS AND ANALYSES

6.1 Deep corer sampling

The purpose of such sampling is to acquire better knowledge of the characteristics inside the pile with regard to both chemical content and geotechnical conditions. It will potentially reveal more information about historic drilling discharges and establish the contamination status in deeper and central sections of the pile. This could be particularly useful in ensuring a comprehensive knowledge base if cuttings pile management options include the possible relocation or removal of the total cuttings volume.

Generally speaking, deep corer sampling of cuttings piles is much more challenging in terms of sampling execution and compared with short corers. It is also significantly more costly. The need for such sampling should therefore be clarified during the early stages of survey planning in dialogue with relevant stakeholders.

If the likely cuttings pile management option is to leave it undisturbed *in situ*, however, shallow sampling will generally obtain sufficient samples for a chemical description. In piles with OBM, the oil degrades very slowly and shallow samples are likely to collect representative and contaminated material (although limited to the uppermost layer). Some options for deep coring tools are presented in appendix A.

6.2 Faunal sampling

The change/gradient in faunal composition identified by environmental monitoring in the approach to some platforms is also pronounced when moving into the area of the cuttings pile. The general finding is that faunal life on the cuttings pile has deteriorated, with fewer species (but possibly in great abundance) and with different prevailing species than in the adjacent area. Opportunistic species which can tolerate sediment disturbance or eutrophicated conditions may be present in great abundance on the cuttings. The presence of the jacket structure and the cuttings material can result in habitat conditions which differ from the surrounding seabed (sand and silt dominates in the North Sea). Together with the chemical content of the cuttings, this influences faunal composition on a pile compared with the natural seabed.

Generally speaking, quantitative sampling of fauna on a cuttings pile is challenging with regard to offshore handling of samples, since OBM cuttings are often sticky and oily. The need for a description of fauna on the pile itself should be thoroughly evaluated before such a survey. Knowledge of the faunal community is useful when evaluating environmental effects, with regard to both the present position (undisturbed/stable condition of the pile) and which species would be affected during possible subsea activity (such as dredging).

ROV-operated corers collect over too small an area to be useful for analyses of macrofaunal composition. A grab or box corer should therefore be used. Procedures for faunal sampling and analyses are described in ISO 16665, OSPAR 2004 and the NEA 2015 guideline.

The standard method for offshore faunal sampling utilises a grab and five replicates. With some cuttings piles, however, a grab could be difficult to use because of limited access for sampling and physical hindrances. Furthermore, sieving to extract macrofauna – larger than 1mm – may be difficult because the cuttings can be compact, sticky and oily. In addition, handling grab samples generates contaminated wash water which should be collected and treated.

Sediment profiling images (SPI) is another technique which can provide information about faunal activity (bio-turbation depth) and oxygen conditions in the top layer (such as BHQ) of the cuttings (see appendix B). This method is efficient and can cover a relatively large area within a limited timeframe, but no quantitative data on the fauna are collected.

6.3 *In situ* measurements

Parameters such as shear strength, oxygen, sulphide content and redox potential should be measured to support the characterisation of the cuttings material. Appendix B presents some relevant field measurement methods for these.

6.4 Seabed surface sampling adjacent to a cuttings pile

Since discharges of hazardous substances from drilling have been reduced, the area of significant contamination is smaller than it was some decades ago. However, the dispersion and distribution of particles and remnants of drilling fluid discharges can extend far beyond the area indicated by the topography of the cuttings pile. The transition zone between the pile itself (based on topography) and the area covered by regular environmental monitoring can be surveyed if this information is requested. A mix of or layers comprising native sediments and cuttings can be found at the border of the pile. Barium from the barite used is an excellent tracer for drilling discharges and can be found in elevated concentrations beyond any traceable effects on the benthic community.

If the transition zone between the cuttings pile and the natural seabed is to be investigated, results from regular environmental monitoring should be consulted. In other words, should no contamination be detected at a distance of 250m, for example, the survey should start with this as its outer point and collect samples at intervals (every 50m, for example) towards the pile. These samples should preferably be collected and analysed for contaminants and physical parameters in the same way as in regular environmental monitoring.

The need for faunal analyses of the transition zone should be evaluated and, if relevant, should be treated in the same way as in regular environmental monitoring.

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APPENDIX A. GENERAL INFORMATION ABOUT OPTIONAL SAMPLING METHODS AND EQUIPMENT

This section summarises some information about sampling tools and methods. However, a great deal more information may exist for each method than this summary can provide. Other documents should therefore be consulted for further details about the various techniques. The recent DECC report on OSPAR OIC characterisation of cuttings piles also lists some available sampling techniques, with their advantages and disadvantages (Genesis 2016). OGUK carried out a review of various mapping and coring techniques for drill cuttings piles in 2013 (OGUK 2013b), which could be consulted before any such survey.

Sampling may be performed with such techniques as:

- grab sampling (surface samples, penetration to less than 20cm) – 0.1m^2 van Veen grab, Day grab or Smith-McIntyre grab are the recommended tools (NS-EN ISO 16665).
- box corer (surface samples, penetration to less than 50cm)
- gravity core sampling (maximum penetration 3-5m in soft sediments)
- ROV-operated coring tubes (described in the main sections of this document)
- vibrocore sampling
- ROV-operated Stinger tool
- hammer sampling
- rock coring.

Figure A-1 shows some examples of sampling tools used for cuttings piles, and figures A-2 and A-3 present some grab sampling images.

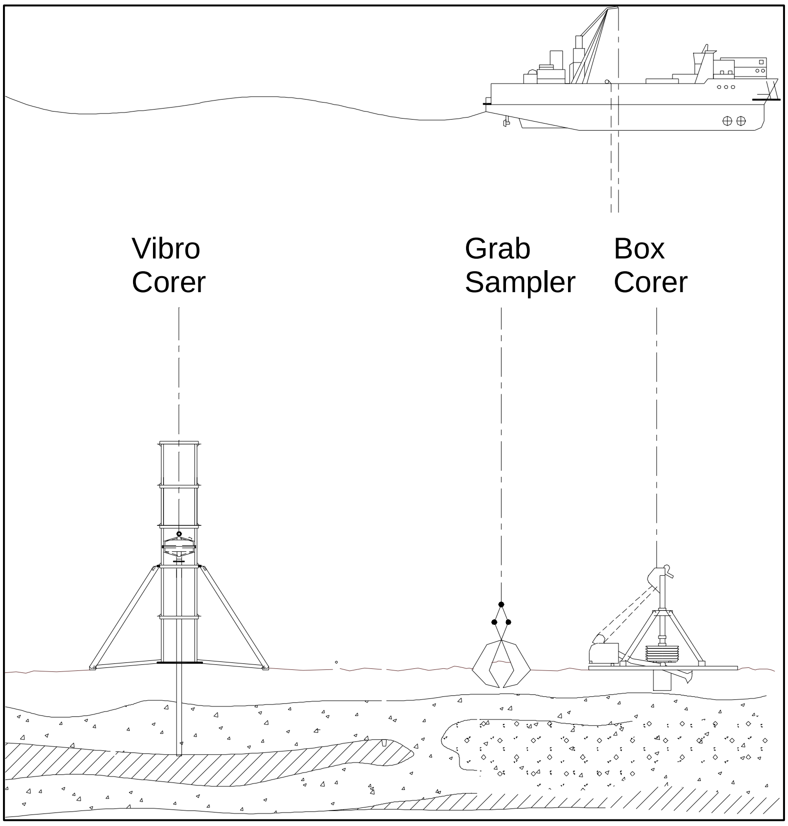

Figure A-1. Sampling tools used for cuttings piles.

Figure A-2. Grab sampling of drill cuttings surfaces at G4 (left) and G5 (right). The positioning accuracy and ROV visual inspection permit grab replicates to be positioned adjacent to each other. Note the slope of the pile at G5.

Figure A-3. A cross section of a grab sample with "healthy" oxygenated sediment at the top and black cuttings material below.

Core sampling of a cuttings pile serves two purposes, which may require shifting between alternative types of corers. Sampling of pile surface material for analyses related to biodegradation and leaching of contaminants should be done with a lighter gravity corer, which takes samples without disturbing the sediment surface. If a box corer is used for faunal sampling (see below), sub-samples may be taken from the box on deck by a handheld corer for surface-related analyses. Further guidelines on surface sediment sampling can be found in NS-EN ISO-5667-19:2004.

Sampling of deeper layers in the pile will normally call for heavier gravity corers or alternative corer technology. In some circumstances, core sampling may not be feasible. The occurrence of larger objects and cement in the pile may prevent coring altogether. Firm, claylike strata in the pile may also cause plugging of the corer and prevent material below from entering it. In addition, material with low cohesion may be lost when the corer is retrieved. In such cases, the description of the deeper part of the pile will have to be based on *in situ* probe tests, such as CPT.

Samples for analysis of bottom fauna should be taken with a grab or a box corer, as recommended for regional environmental monitoring. Heavy-duty offshore grabs, such as the van Veen grab or similar, are best suited for sampling sandy and mixed sediments, while box corers are best suited for softer sediments and especially when larger undisturbed cores are required. Ensuring that the gear has been fully closed when lifted from the bottom is important for avoiding sediment surface disturbance and loss of material. The minimum sampling area should be $0.1m^2$.

A brief technical description of the most relevant sampling and *in situ* testing techniques for a cuttings pile survey is provided below.

Vibrocorer

The vibrocorer uses vibration to drive a sample tube into the seabed. Typical systems comprise a steel core barrel 7-100mm in diameter and 3-6m long. Inside the core barrel is a tightly fitting plastic tube or "core liner", which is preferably transparent but may be opaque. This is held in place by a "cutting shoe" at the end of the barrel which also incorporates a sprung steel "core catcher" sample retention device. On top of the barrel is a vibratory motor incorporating a contra-rotating asymmetrical weight, which is driven electrically or hydraulically. The motor and core barrel are usually encased in a tubular steel deployment frame with a tripod or oblong base to ensure stability and verticality.

This equipment is deployed on a single steel lifting cable with an associated electric or hydraulic umbilical cable. Once on the seabed, the vibratory motor is activated and the barrel penetrates through the combination of vibratory effect and motor weight. On recovery to the surface, the core barrel is removed and replaced by another ready for redeployment. The internal core liner is extruded and usually cut into sections for core description, testing and/or sealing for transport to a land-based laboratory.

Available system enhancements include higher frequency motors to improve penetration in sands, and percussion attachments which usually comprise a spring and reciprocating weight arrangement between motor and core barrel to improve penetration in stiff clay.

<u>Advantages</u>

- Maximum penetration of about 6m.
- The method is relatively simple, inexpensive and lightweight (typically around 0.75-1.25 tonnes in air). Lifting capacity must allow for barrel retraction forces and the weight of the cored sediment. A vibrocorer can be a very cost-effective method of recovering some material in most types of sediment.

<u>Disadvantages</u>

- Penetration may be limited in dense cohesionless strata or very stiff clays, so that samples of critical strata fail to be recovered.
- Accurate definition of sediment stratification may be impaired by plugging, compaction or core loss, causing sections of the sediment profile to be missed or misinterpreted.
- The vibratory method induces disturbance in the sediment, which means that subsequent laboratory tests for parameters such as shear strength and consolidation characteristics may produce unrepresentatively low values.
- Where some vessels are concerned, the equipment can prove cumbersome to handle – particularly the longer-barrelled models. Some 6m vibrocorers, for example, have a total height of around 7.5m and a maximum base width of 5m.

Gravity corers

The standard gravity corer normally comprises a core barrel, a liner and a cutting shoe, very similar to those used with vibrocorers. One large weight or a series of adjustable smaller weights sit atop the core barrel, and usually total 0.5 to one tonne. They are deployed on a single steel lifting cable and penetration is achieved by allowing the unit to freefall the final 5-10m to the seabed. Surface sediment corers are generally somewhat smaller and lighter. They should be completely open during deployment in order to strike the sediment with a very modest bow wave to catch the boundary layer.

The stationary piston (or Kullenberg type) corer operates with a trip-release mechanism. It differs from a standard corer in having the core barrel closed at the bottom by a piston, which is connected to the main lift wire and remains approximately stationary as the core barrel penetrates the seabed. The presence of the piston can create a partial vacuum between it and the top of the sediment core, giving improved recovery in some seabed conditions.

Advantages
- Quick, inexpensive and simple, and does not cause so much disturbance in soft clays as a vibrocorer.
- Maximum penetration 5-6m in soft sediments (note that larger gravity corers exist which can take cores 35-40m long. These require larger vessels).

Disadvantages
- Poor penetration in stiff clays or granular sediments.
- Recovery is smaller than penetration in some sediments.
- A free fall (freewheel-equipped) winch is required.
- If a trip-release mechanism is used, it can be cumbersome to handle on deck and potentially dangerous because inadvertent triggering is a possibility.

Grab sampler
Put simply, the grab sampler is an articulated bucket which closes when it comes into contact with the seabed and thereby collects a sample of surface deposits. These samplers can range in enclosed volume from a few litres to a cubic metre. Closure is activated by a simple trip mechanism or by hydraulics in some larger units. Recommended types have a lid arrangement which prevents washout of material during lifting.

Advantages
- Usually relatively small, simple, inexpensive and easy to operate, although less so for larger hydraulic units. However, the latter have the advantage of greater and more consistent recovery.

Disadvantage
- Sample recovery tends to be hit and miss.
- Very shallow penetration.
- Very disturbed sample.
- Potential for washout of the finer fraction of the recovered sample, rendering analysis of particle size distribution unreliable.

Seabed rock corers
A variety of these are available on the market, ranging in size from around one to 13 tonnes and theoretically capable of taking cores with diameters ranging from 25-150mm and from penetrations of up to 9m. Most incorporate a rotary drive mechanism and diamond or tungsten-carbide impregnated drilling bits plus an inner core barrel. Their main advantage is the ability to take cores of rock outcroppings at or near the seabed without recourse to a fixed or floating drilling platform. The primary disadvantage is their variability in performance and recovery. Lack of direct control over and ability to vary drilling parameters, such as bit pressures, flushing fluid flow rates, rotation speeds and drive rates on many systems, mean core recovery can be very variable. The size and weight of some systems can also be a disadvantage.

Box corer
This is a relatively lightweight sampling system originally developed for oceanographic research. It is designed to push a metal box about 0.5m into the seabed and seal in the sample on retraction with a blade-like door which closes beneath the box. Sample volumes are typically in the range 10- 50 litres.

Its main application is the retrieval of good-quality block samples from soft clay in a manner which also permits inspection of a relatively undisturbed section of the seabed surface. The main disadvantage is its limited penetration capability.

Selcore hydrostatic hammer corer
The Selcore sampler is a drop corer equipped with a hydrostatic motor driving a hammer. Like a gravity corer, the Selcore sampler should fall freely from a convenient distance above the seabed. The hydrostatic hammer is activated automatically when the core barrel hits the seabed, and hammers the corer into the seabed sediments. Energy is derived from the pressure difference between the air in the low-pressure chamber and the ambient hydrostatic pressure at the depth where sampling takes place. The Selcore is available in different sizes from 500-2 000kg.

<u>Advantages</u>
- The Selcore is operated without hydraulic hoses, electric cables or batteries.
- It is capable of obtaining samples 12-15m long
- It can be operated from a crane over the side of a vessel, but requires some free-fall facilities from crane or winch.

<u>Disadvantages</u>
- Some problems initially arose in controlling energy from the motor, resulting in overpenetration or severe hammering into bedrock. Later versions may have improved this.
- Like other coring equipment, penetration in soft sediments may be greater than recovery.
- System operation requires a minimum differential pressure equivalent to a water depth of at least 120m. A power pack will be required in shallower depths.

Cone/piezocone penetration test (CPT/PCPT or CPTU) and envirocones
Cone penetration testing involves measuring the resistance to controlled penetration of the ground by a steel rod with a conical tip. Standard electrical cone penetrometers incorporate internal load cells which measure resistance to the cone and side friction on a sleeve behind the cone. The piezocone version also measures excess pore water pressure in the ground generated by penetration of the cone. Standard cones have a cross section of 1 000mm^2 or 1 500mm^2, although some new systems use cones with an equivalent area of 100mm^2.

As a test proceeds, usually at a standard penetration rate of 20mm/sec, continuous measurements of tip resistance, sleeve friction, excess pore pressure and penetration distance are transmitted to the surface in real time via an umbilical cable.

The CPT/CPTU is an excellent device for logging layering. Parameters such as sediment type, relative density, shear strength and stress history can then be derived from the direct measurements and calculated ratios using empirical correlations.

<u>Advantages</u>
- Usually guarantees greater penetration.
- Provides a complete stratigraphic profile (continuous measurement).
- Gives data in real time, permitting almost immediate interpretation of ground conditions.
- Can reduce the amount of time-consuming laboratory testing.
- Provides the only reliable method for determining the relative densities of cohesionless sediments.
- Testing is very rapid and, depending on test spacing, the seabed unit may be left outboard between tests.
- Additional sensors may be added to the cone to give indications about the degree of contamination (electrical resistivity and fluorescence probes, for example).

Disadvantages

- Weight. Although lightweight system are available, five- to 10-tonne units are typically required to ensure sufficient reaction force and thereby achieve the desired penetration in dense sands/stiff clays.
- Cost. The technical complexity and precision engineering involved in many of the components inevitably make it a pricier item of equipment which requires several highly trained personnel to operate. (However, trends towards lighter and simpler systems are beginning to mitigate these particular disadvantages.)
- A competent geotechnical engineer is normally required to process and interpret the test data.

Drilling and wireline sampling and testing

Drilling and testing through the drillstring with wireline-operated equipment from a dedicated geotechnical drilling vessel is an alternative to crane-operated techniques. Standard sampling and *in situ* testing techniques developed for geotechnical drilling can be used in surveying medium to large drill cuttings piles. A seabed frame is required to guide the drill pipe at the seabed, and to provide the necessary reaction force when pushing the sample tube or a probe into the sediment. The testing and sampling are performed inside and ahead of the drill bit into the bottom of the borehole.

Advantages

- The technique is capable of sampling and testing in most sediments.
- Able to obtain samples and perform testing through the cuttings pile and into the underlying seabed deposits.
- Efficient operation, with a high production rate.
- Can deploy gravity corer and vibrocorer sampling over the side while drilling and testing.

Disadvantages

- Requires a large, dedicated drilling vessel, most commonly DP-operated.
- Higher mobilisation costs and dayrates.
- Operational restrictions on distance from the platform.

APPENDIX B. OPTIONAL ANALYTICAL METHODS AND OFFSHORE MEASUREMENTS

Refer to the NEA guideline, OGP 2012 and OSPAR 2004 on offshore environmental monitoring for analytical procedures. Some methods are listed briefly below.

Physical characteristics (density and shear strength)
The purpose of geotechnical testing is to determine relevant parameters in order to evaluate the strength, density and stability of the cuttings pile (in other words, its physical characteristics). Testing can comprise classification and index testing to describe the consistency of the cuttings material, or direct simple shear and consolidation tests as input for evaluating the internal strength of the material and the stability of the cuttings pile.

Relevant parameters to be investigated, which will also support the interpretation of chemical results, are presented below.

Parameter	Purpose	No of samples	Comments
Density	Will support geotechnical data on pile material stability and estimating the (chemical) contaminant load	Limited number of samples	On land
Shear strength	Will support geotechnical data on pile material stability and can provide useful input for assessing the feasibility of pulling jacket members through the pile.	Top layer of the pile	Offshore (preferably) or on land
Water content	Will support geotechnical data on pile material stability, and enable calculation of (chemical) contaminants on a dry weight basis	All samples where contaminants are measured	On land

Faunal characterisation
Depending on the position at the 250m monitoring station, macrofaunal sampling should be included as an optional part of cuttings pile investigations. The macrofaunal community is known to be influenced by the discharge of drill cuttings.

The purpose of biological characterisation is to classify fauna at the pile surface and relate this to the surrounding areas and the time since discharge ceased. Furthermore, consideration should be given to the recolonisation potential of the cuttings pile.

Biological analyses should concentrate on the structure of the bottom fauna in the samples taken on the pile and in adjacent areas. Sampling and analysis methods should accord with national regulations (such as the NEA guideline).

Assessment of hydrocarbon leaching rate and persistence of contaminants
Oil and Gas UK has reviewed technologies for measuring hydrocarbon leaching rates from cuttings piles (OGUK 2013a). This report presents available, emerging and potential techniques for determining loss of oil from cuttings. The UKOOA phase III survey of cuttings piles also presents methods and discusses some challenges with leaching measurements (RF 2004). These documents or other relevant sources should be consulted before selecting methods for such analyses.

Persistence of the contaminated area (seabed with THC greater than 50mg/kg) can be mapped with repetitive sampling over time and/or modelling.

Sediment profile images (SPI)

The vertical zoning of the sediments can be studied using SPI, where a camera collects photographs of vertical zoning in the upper part of the seabed. This technique can be useful for a relatively rapid survey of environmental conditions (BHQ) in the top section of the sediment/cuttings.