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The Norwegian Oil Industry Association

Guidelines for characterisation of offshore drill cuttings piles

Final report May 2003

Preface

In October 1999 the Norwegian Institute for Water Research (NIVA) and the Norwegian Geotechnical Institute (NGI) developed the first version of the OLF document "A Guidance Document for Physical, Chemical and Biological Characterisation of Offshore Drill Cuttings Piles". OLF issued Version 2 of this document in May 2000 with amendments agreed upon by the OLF Steering Group, NIVA, NGI and Rogaland Research (RF).

During the recent UKOOA R&D JIP on drill cuttings the knowledge about cuttings piles has increased. It was therefore found appropriate to further develop the characterisation guidelines into a practicable management tool in line with this new knowledge.

The OLF working group for handling of drill cuttings has been responsible for the update. RF has contributed with valuable input and Det Norske Veritas (DNV) has had the secretariat function during development of these guidelines.

OLF want to thank all that have contributed in this update; all participants at the workshop that was arranged by RF in February 2002, and Grethe Kjeilen (RF), Stig Westerlund (RF), Torgeir Bakke (NIVA), Bob Hemmings (UKOOA) for their valuable input. We want to thank Steinar Nesse (DNV) for professional coordination and rewriting during the updating process. Thanks also to Rosamund Jensen (ConocoPhillips) for improving the English language in this document.

Stavanger, 7 January 2003

The OLF working group for handling of drill cuttings

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Abbreviations

CP	Cessation Plan
EIA	Environmental Impact Assessment
JIP	Joint Industry Project
OBM	Oil Based Mud
OLF	The Norwegian Oil Industry Association
PAH	Polycyclic aromatic hydrocarbons
PDO	Plan for Development and Operation
PU-foam:	Poly-Urethane foam
SPE:	Solid Phase Extraction
SPMD:	Semi-Permeable Membrane Devices.
THC	Total Hydrocarbons
UKOOA	United Kingdom Oil Operators Association
WBM	Water Based Mud

1 Introduction

1.1 Background

Drill cuttings originate from the drilling process when the drill bit is driven down through the ground producing rock fragments and associated drill fluid back to the rig. Over the past decades, different type of drill fluids have been used and discharged. Environmental impacts from such discharges have resulted in stricter regulation, reducing and gradually eliminating harmful discharges. However, beneath and adjacent to many offshore petroleum installations piles of cuttings with varying contents and at varying volume have accumulated. Such piles may represent a management issue when planning for field cessation. Different cuttings piles management options exist and evaluation often depends on the characterisation of the pile; its size, what is in it and what is the risk to environment?

In 2000 NIVA and NGI developed an OLF guidance document for characterisation of drill cuttings piles /1/. The guidance document has valuable sampling strategies, analysis discussions and method descriptions. However, as the knowledge about cuttings piles has improved during the recent UKOOA R&D JIP on drill cuttings /2/ it has been considered appropriate to further develop the Characterisation guidelines into a practicable management tool.

1.2 Drill cuttings pile management planning

In North Sea countries with offshore petroleum activities field decommissioning and disposal are regulated in accordance with the OSPAR 98/3 Decision. The regulative process varies somewhat between countries, however the "Cessation Plan" may be considered similar in its contents and purpose. The plan will reflect the process evaluating and documenting disposal alternatives and the recommendation of a solution. This is also relevant to the issue of drill cuttings piles. The stage in the field life cycle at which the current guidelines apply is indicated in Figure 1.

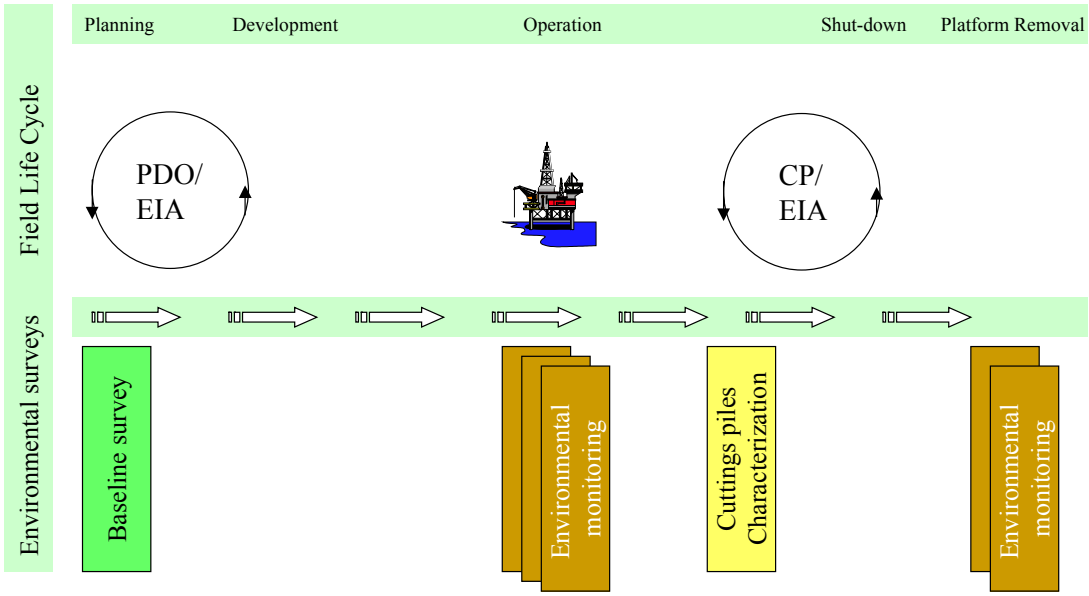

Figure 1. Characterisation of cuttings piles in the "field life cycle" process and related to other relevant environmental surveying.

The cuttings piles characterisation is a step in the process in developing the Cessation Plan. The characterisation of the cuttings pile describes the present situation (quantity, quality). The evaluation of disposal options for the cuttings piles will be part of the EIA process related to the Cessation planning. The OLF Handbook in EIA gives further guidance in this process /7/.

The guidelines recommend a level of sampling and parameters for analyses based on the UKOOA R&D JIP results (see section 1.4 below). It is however the responsibility of the operator or license to decide on the magnitude of work and resources to be invested and to establish the detailed plan for cuttings piles characterisation. This should also take into consideration the further field cessation activities, including evaluation of cuttings piles disposal alternatives and field installation disposal evaluations (figure 2).

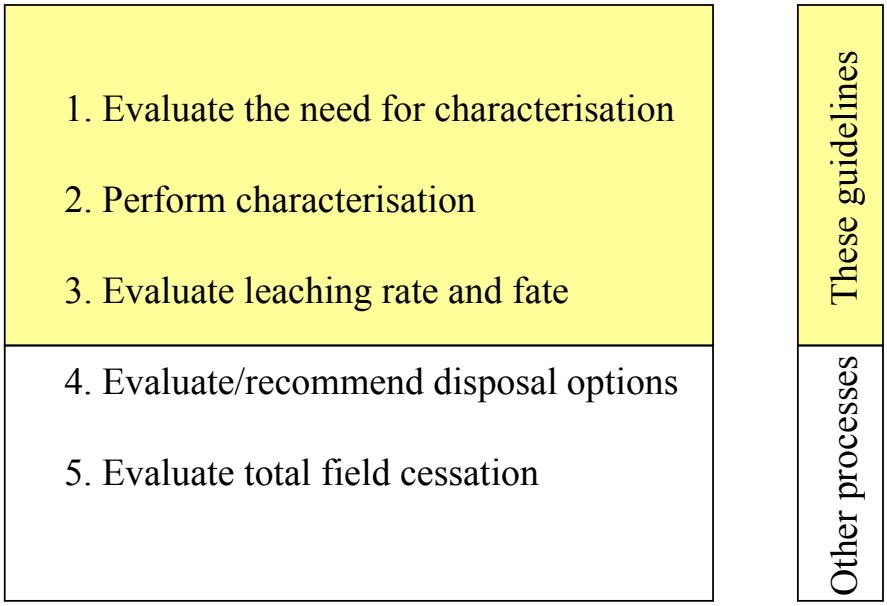

Figure 2. The processes of the current guidelines (yellow) and subsequent activities.

1.3 Objective

These guidelines shall serve in the process of planning for a sound management of drill cuttings piles as part of the total cessation planning.
The guidelines shall specifically recommend an approach for characterisation of drill cuttings piles as input to this planning process, including the evaluation of historic data, field sampling and laboratory analyses.

The guidelines should help the operator describing:

- Exact position of pile
- Pile volume
- Pile area / topography
- Physical characteristics (density, shear strength)
- Chemical contents of the pile (THC, PAH, etc)
- Biological characterisation

The guidelines should also assist the operator to evaluate the following:
- Leaching rate of petroleum hydrocarbons
- Persistence of contaminated area

On these issues some methods are available and presented in these guidelines, however more experience is considered necessary before one can recommend on exact methods for the given situations. The guidelines should therefore be updated on this issue when they have been practised for a period of time.

1.4 Premises

These guidelines shall benefit from the knowledge being gained through the UKOOA R&D JIP on drill cuttings. The main conclusions from this 6 million GBP initiative, which have been subject to independent accreditation, will thus form the basis for the guidelines. The main conclusions from the JIP of relevance to these guidelines are in short /2/:
- Hydrocarbons are prime contaminant
- Hydrocarbons present are closely associated with the fines, low hydrocarbons leaching rates were observed
- Fate is determined by the physics of dispersion, enabling subsequent degradation of hydrocarbons
- Frequency and strength of physical disturbance is related to water depth. Beyond 70m it is rare for wave/ currents to be able to move cuttings, but extreme storms may move cuttings in all areas
- Potential impacts of metals are small both in comparison and absolutely

Based on these conclusions UKOOA has further recommended that a comprehensive programme of sampling and surveying around installations that have discharged OBM cuttings is initiated. The results will serve in selecting the best management option on its merits. Factors should include nature and volume of hydrocarbons, local hydrography, facilities etc. These aspects are covered by the present guidelines.

Synthetic muds are based on olefins, ethers or esters. They are generally much more naturally degradable than base oils however the degradation may result in local oxygen depletion. Biological effects in areas where such muds are discharges are generally less than for oil based muds but higher than for water based muds /3/.

Cuttings piles generated from discharges when drilling with WBM generally do not a potential for significant environmental impacts. However, in addition to their contents their size may make an issue that needs to be evaluated in the cessation planning. Cuttings piles generated from WBM drilling thus have less focus but are still included in the present guidelines.

2 Evaluation process

The approach chosen is a stepwise evaluation to eliminate cuttings piles with low environmental risk from further investigation. The intention is to identify cuttings piles that may represent an environmental risk. The steps in the evaluation process are:

1) Pre-screening process to qualify cuttings piles that do not represent a significant environmental risk, and therefore do not need further investigation; Group A piles.
2) Further evaluation of cuttings piles that need more thorough review as to qualify/dis-qualify as low risk cuttings piles; Group B piles.
3) Differentiate cuttings piles that need further field investigation, and establish magnitude of characterisation recommended; Group C piles.

2.1 Pre-screening, Step 1

The pre-screening process evaluation will be based on information about drilling history and type of development.

A cuttings pile can be classified as an "A-pile" if water based mud only has been used during all drilling campaigns at the installation/field. This is mainly relevant for single well developments, pre-drilled template developments but also for more recent multi-well developments.

The pre-screening requires excellent book-keeping with regard to discharge history. If there is any reason to believe that the cuttings pile material might be contaminated, the evaluation should continue with Step 2.

Further screening is required (Step 2) if synthetic or oil based muds are used.

2.2 Screening, Step 2

Step 2 will further separate piles that need to be surveyed from piles where no further cuttings piles investigation is necessary. This situation is applicable for piles where OBM or synthetic mud has been discharged.

The following criteria should be taken into consideration:

Monitoring results

At many offshore fields environmental monitoring is performed regularly, including seabed sampling and analysis on chemical and biological parameters. In Norway such monitoring is a regulatory requirement. Results from these investigations give a good indication of the contamination level around the fields cuttings piles. The stations closest to the field drilling installation give the best picture, i.e. normally the 250m stations. In the UKOOA JIP it was agreed that a THC concentration below 50 mg/kg does not represent a significant environmental impact. This level is applying for sediment depth; 0-1, 1-3, 3-6 cm. For a THC

concentration above 50 mg/kg* the cuttings pile qualifies as Group C, and offshore sampling is recommended.

For piles where synthetic muds have been used the corresponding level of contamination is equally 50 mg/kg.

Time period since drilling

Time period since last discharge is another factor that can be important to consider. As the hydrocarbons naturally degrades the concentration will be reduced over time. Trends in concentration reduction can normally be seen from regular monitoring around the field.

"Other discharges" from the field operation

Knowledge about other significant discharges of petroleum hydrocarbons during the field operation (drilling, production, etc.) which may have resulted in hydrocarbons being trapped in the cuttings piles could be important. Annually, during field operation the operator is required to report any accidental discharge and to keep a track record of all regular and accidental discharges. If a review of this information indicates that the cuttings pile may have received oil, chemicals or other substances that may have contaminated the cuttings an offshore survey is recommended (Group C pile).

* The 50 mg/kg limit is important to establish in the further evaluation of environmental significance with regard to distribution and persistence of THC contamination (see Chapter 6).

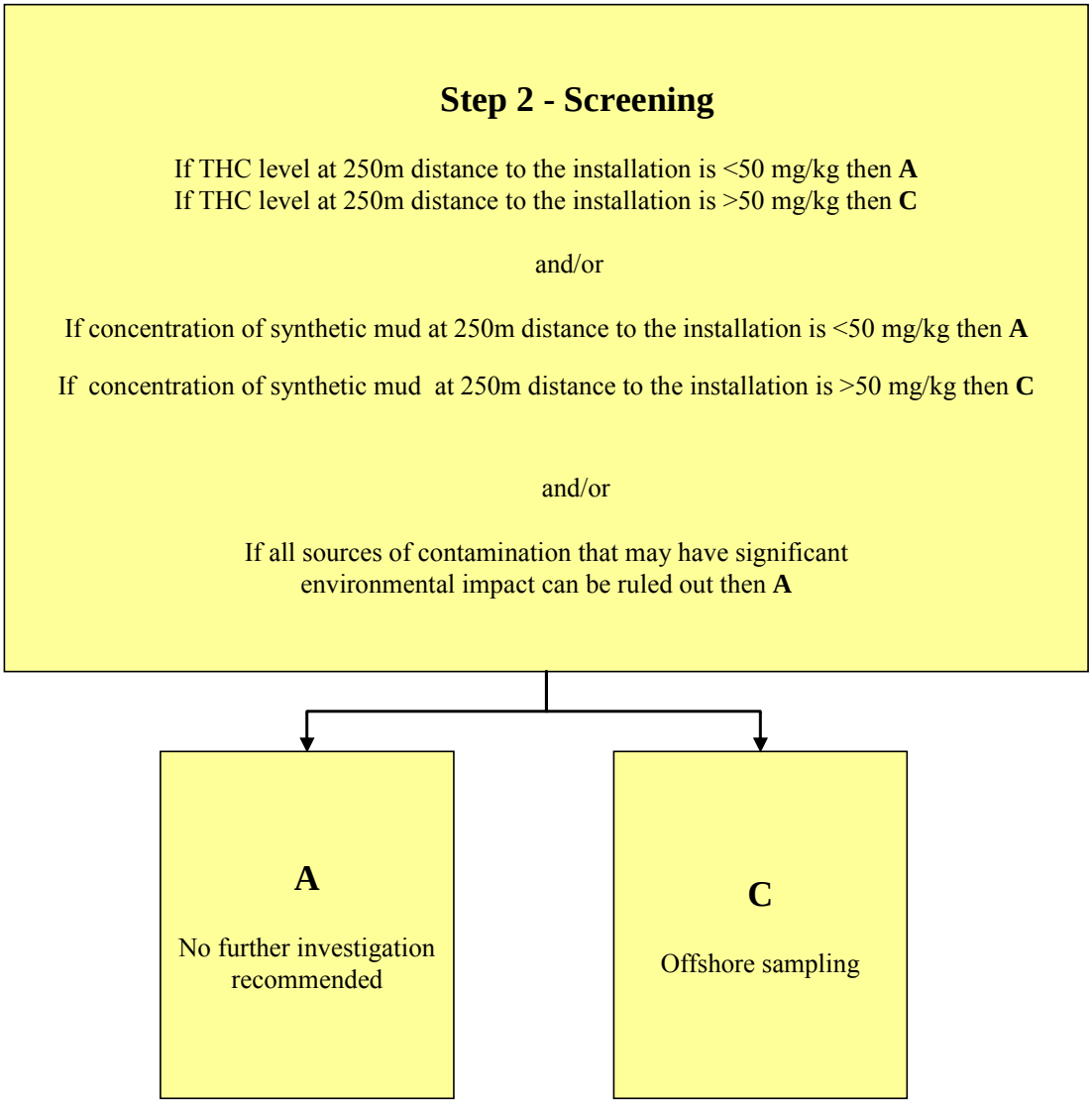

Figure 3. Cuttings piles characterisation process. Step 2: Further evaluation.

3 Field sampling

3.1 General considerations

The location of a cuttings pile relative to the platform/structure will vary with type of structure, i.e. subsea seabed structure, steel jacket or Gravity Base Structure (GBS), and the location (position and height) of the discharge pipe above the sea bed. For a seabed structure and a jacket the cuttings pile will be located within and to the side of the structure/jacket-legs, most likely stretching out in the direction of the prevailing current. For a GBS the cuttings will gather on one side of the base of the platform where the cuttings have been dropped, possibly with some of the cuttings gathered on top of the domes of the GBS. In the sampling strategy described here, it is assumed that there is very little access to sample the cuttings located within the footprint of a steel structure. Therefore, for practical purposes, the same approach is used when planning a sampling survey at drill cuttings piles at all type of structures. Some modifications will have to be made to the plan to adapt to local requirements set forth in each case.

3.2 The sampling strategy

The main objectives for a sampling program at a drill cuttings pile are to:

- obtain surface sediment samples from the upper 20cm of the deposit for chemical, biological and erosion analyses
- obtain long core samples for chemical and physical characterisations.

Cuttings piles screened out during Step 1 do not require any specific mapping, however acoustic profiling may optionally be performed to document that no pronounced pile is present. This mapping will describe the pile with respect to location and depth, and how it is positioned in relation to the field installations. This information could prove valuable also in the platform removal/disposal planning and execution.

For fields with piles with a discharge history indicating some potential environmental harmful contents, a field sampling survey should be undertaken in addition to the location and pile topography mapping. Field sampling with subsequent analyses of samples will further as appropriate determine physical, chemical and biological structure of the pile.

The results from point sampling and analysis of the pile for physical, chemical and biological characterisations, will be used to define the limit of areas contaminated (especially for hydrocarbon) or effects on the macro fauna, together with a more detailed characterisation of the cuttings piles.

The station network shall preferably be a radiating transect design with one axis along the main current direction at the bottom and one axis perpendicular to this. The numbers of station increase with increasing category cuttings pile size, see Table 1.

Number of stations needed should follow a strategy of redundancy sampling, i.e. to take more samples than is required in the analytic program. The number of stations recommended in table 1 should therefore be understood as number of samples to be analysed. Planning of the sampling locations should be based on the historical data review, information from geophysical surveys of the cuttings pile and local accessibility.

Based on their size the cutting piles are divided into different categories, see Table 1.

Table 1. Number of stations to be sampled from different size cuttings piles.

# samples	Mapped pile volume (m^3), cf section 4.1				
	Category I	Category II	Category III	Category IV	Category V
	<1000	1000-5000	5000-20,000	20,000-50,000	>50,000
Surface sediment (0-20 cm)	4	8	12	12	16
Vertical samples (0-X m)	2	2	3	3	4
Biological samples	2	4	4	4	8

The exact number of station must be set according to the shape of the cuttings piles. In figure 4 an example of a grid system is given.

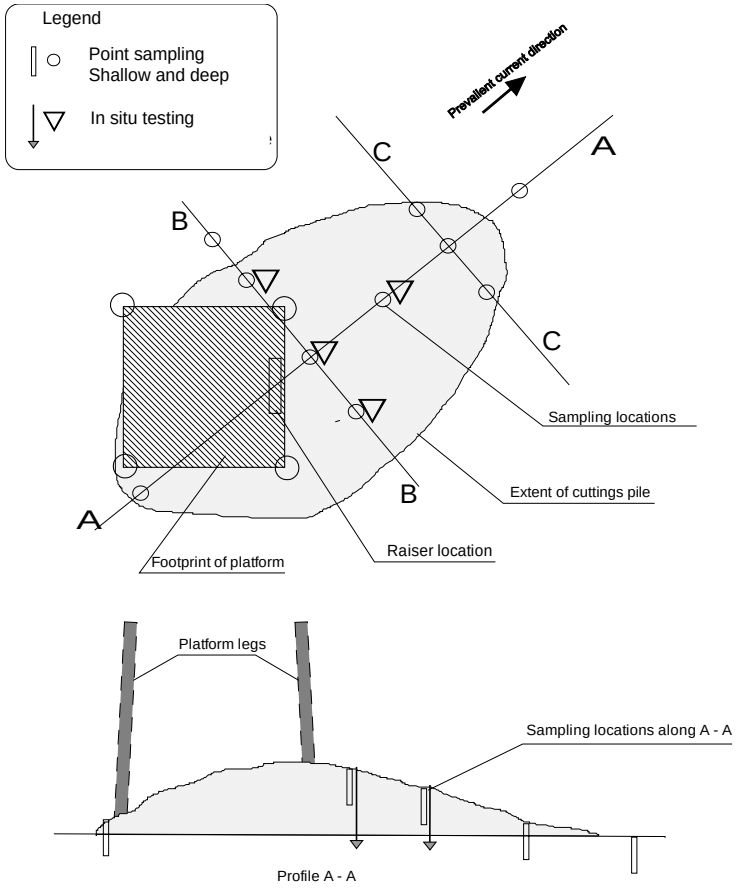

Figure 4. Illustration of a possible sampling scheme for a medium to large cuttings pile.

Seabed surface sampling

The dispersion of hydrocarbons will be much wider than the main cutting piles itself. The outer edge is, in general, not well defined. To monitor areas contaminated with environmental harmful contents, sediment stations shall be placed in a way that includes the expected contaminated areas. Number of stations that is recommended reflects both that the sampling is taking place offshore, and that the equipment both can be heavy and inaccurate with regard to the exact position of the sampling point. The distance between sampling locations should therefor be more than 50m. In certain cases however, one must realise that sampling as close as 50m from the installations is impossible, and that sampling at the periphery of the piles is the only option.

"In pile" sampling

Penetrating the cuttings piles for deep samples is difficult due to layers with different hardness.

Replicated sampling is not considered necessary when the aim is to map the horizontal and vertical composition and structure of the pile for management purposes. Therefore if the budget allows for several parallel samples to be taken at each sampling location one should rather plan for more sampling locations to be included to improve the spatial resolution.

Two different sampling techniques are recommended:

- Deep vertical core sampling preferably all the way through the pile to the original seabed with focus on geotechnical and chemical conditions in the various strata of the pile.
- Grab sampling (< 20cm depth) to assess the bottom fauna conditions at the surface of the pile, and to define the limits for contaminated or effected areas.

For small drill cuttings piles located within the footprint of the platform, sampling may prove to be difficult. In such cases sampling and testing may be limited to shallow sampling underneath the platform by use of ROV, or from the platform deck (for instance through hatches in the deck).

Sampling may be performed by use of crane operated sampling techniques such as:

- grab sampling (surface samples, penetration to less than 20 cm)
- box corer (surface samples, penetration to less than 50 cm)
- gravity core sampling (maximum penetration 3 to 5 m in soft sediments)
- vibrocore sampling (maximum penetration is 5 to 7 m outside jacket)
- hammer sampling (Selcore sampler, penetration to 9-12 m)
- rock coring (maximum penetration is 5 m, operational depth restricted to about 100m)

Figure 5 shows some examples of sampling tools for use in cuttings piles

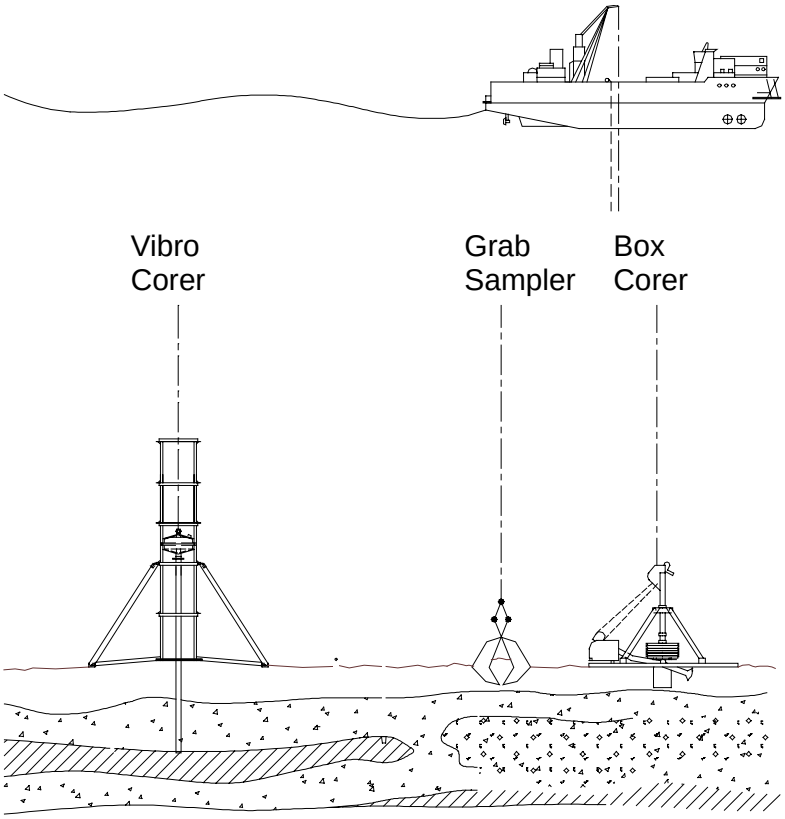

Figure 5. Sampling tools for use in cuttings piles

3.3 Sample preparation and analyses, quality assurance

Sample preparation and analyses

Biological and sediments samples should be handled according to good laboratory practice in a manner suitable for the analysis they will undergo. Handling and preservation of samples will differ with different analytic protocols (see Appendix 2).

Quality assurance

Consultants who shall perform elements of a cuttings pile survey should document that they are accredited or in other ways certified regarding quality assurance (e.g. according to the ISO 9000 principles) for the specific field work, analytical services or other tasks requested. In some instances this is already taken care of by the operators' pre-qualification requirements for selection of suppliers. Relevant examples of quality assurance guidance documents for environmental surveys are given by the Nordic Council of Ministers /16/ & /17/ and Norsk Standard 9420. The consultants should also document that they can mobilise the complete resources necessary for the survey, including satisfactory backup of equipment and personnel.

The quality assurance program implemented should be described in the report from the survey.

4 Cuttings piles characterisation

Environmental surveys of the surrounding seabed areas are in principle covered by other guidelines (e.g. OSPAR or for Norway by The Activities Regulations), and there is a strong intent that cuttings pile surveys should be coordinated with existing seabed monitoring programs in a way that ensures comparability among analytical results. Thus when the same analytical parameters are proposed in the cuttings piles Guidelines as in the environmental monitoring the analytical methods are harmonised as far as possible between the two sets of guidelines. Similar harmonisation should be sought when applying these Guidelines in other countries.

4.1 Establishing exact position of pile, pile area / topography

It is important to know the cuttings piles position, shape and size before a more detailed characterisation is carried out.

There are several methods for mapping cuttings piles:

- Acoustic/seismic depth measurement
- ROV-video based mapping

Acoustic or seismic profiling will determine the position, extent and topography of the cuttings pile. ROV video recording will additionally identify visible obstacles or debris that could create problems during sampling and/or disposal of cuttings material.

Some examples of topography plots are given in Figure 6.

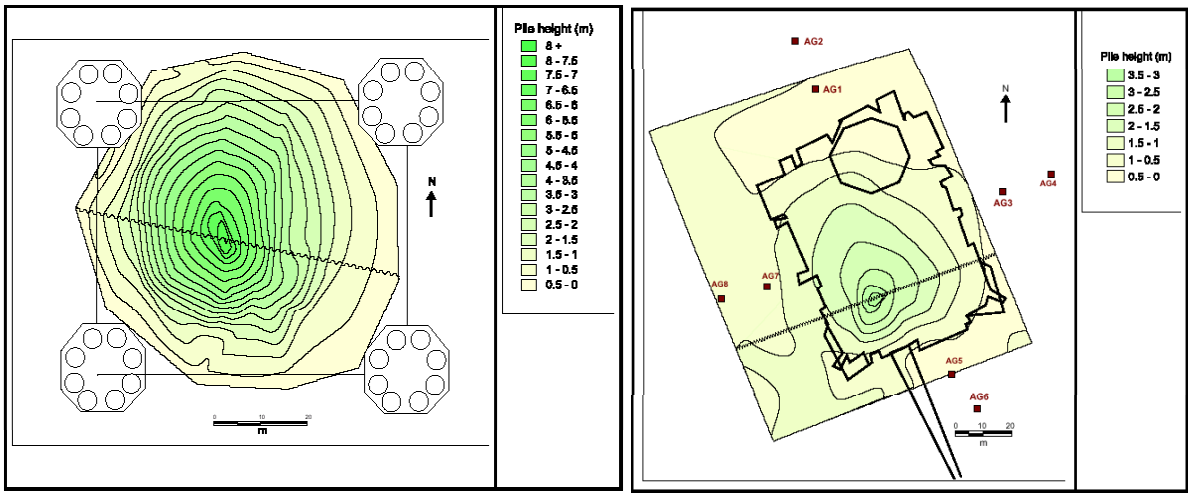

Figure 6. Examples of topography plots for cuttings piles /5/.

4.2 Pile volume

A rough estimate of the cuttings piles volume should be estimated. The edge of the pile area is here suggested as the area with a reduced depth of 0.1m compared with the natural sea bottom in the vicinity or compared with baseline measurement. The pile volume is calculated based on the topography mapping for the pile area.

4.3 Physical characteristics (density, 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 (i.e. physical characteristics). The testing can consist of classification and index testing to describe the consistency of the cuttings material, or direct simple shear tests and consolidation tests as input to evaluate the internal strength of the material and the stability of the cuttings pile.

Relevant parameters to investigate, which will also support in the interpretation of chemical results are:

Parameter	Purpose	# samples	Comments
Density	Will support the geotechnical data on pile material stability and will also support estimation of the load of contaminants (chemical)	Limited number of samples	Onshore
Shear strength	Will support the geotechnical data on pile material stability	Top layer of the pile	Offshore or onshore
Water content	Will support the geotechnical data on pile material stability, and it will also enable calculation of the contaminants (chemical) on a dry weight basis	All samples where contaminants are measured	Onshore
Grain size distribution/ Total organic content	Will support the geotechnical data on pile material stability	Limited number of samples	Onshore

Relevant geotechnical analyses are listed in Appendix 3.

4.4 Chemical contents of the pile

The UKOOA JIP has concluded that the content of petroleum hydrocarbons (THC) in the cuttings pile are the prime contaminants. This is thus the primary target for the chemical analysis of the cuttings pile characterisation, and should be regarded as mandatory parameters.

Parameter	Purpose	Method
Total hydrocarbon (THC)	The basic parameter to estimate the total amount and distribution of oil present in the pile. The analysis will also indicate type of base oil (e.g. diesel, low aromatic, fresh or weathered, and hydrocarbon based synthetic fluids such as olefins).	OSPAR
Aromatic hydrocarbons (3-6 ring PAH)	Information on the content of these potentially bio-accumulative and to some extent carcinogenic constituents of oil is an important input to a risk analysis. Analysis of aromatic hydrocarbons should be done on a subset of samples, selected on basis of the THC analysis. The PAH analysis should focus on the EPA list of 16 potentially hazardous compounds (cf. SFT 1999a, app. 3).	OSPAR

Depending on the discharge history or field history, age of field, or monitoring results from the adjacent area several more parameters should be evaluated for investigation.

Parameter	Purpose
Polychlorinated biphenyl's PCB	This group of compounds is of major environmental concern. The chemical has been abandoned since 1980, however products containing PCB's have previously been used at the North Sea installations. For monitoring purpose the Dutch 7 PCB's should be measured.
Synthetic base fluids	Where applicable, the analysis should cover the types of synthetic fluids used during drilling. Samples of the original base fluids should be used as analytical reference, if possible
Heavy metals	The analysis should give a general overview of the pile content of a wide range of heavy metals commonly found in cuttings waste material: As, Ag, Ba, **Cd, Cu**, **Ni**, **Cr, Hg**, **Pb** and Zn. The metals listed in bold are mainly typical contaminants in barite. They are further on the priority list for emission reduction policies for heavy metals by the United Nations Economic Commission for Europe.
Radioactivity (NORM/LSA)	Scaling processes generates compounds with low level radioactivity (NORM or LSA), measured as Ra^{226}. These compounds can possibly end up in the cuttings pile and may influence on the waste management solution.
Endocrine Disrupters (ED)	ED's are compounds that disrupt the endocrine system. ED represents a broad spectrum of compounds of varied origins. Various industrial chemicals like dioxin and PCB can be sours of ED. ED chemicals appear to be persistent in the environment with bioaccumulating characteristic.

4.5 Biological characterisation

Depending on the situation at the 250m monitoring station macrofauna sampling should be included as an optional part of the cuttings piles investigations. It is known that the macrofauna is effected by hydrocarbon concentrations above 50 ppm. Table 1 outlines the number of stations that should be sampled for different size categories of cuttings piles.

The purpose of the biological characterisation is to classify the fauna at the surface of the pile and to relate this to the surrounding areas and time since discharge ceased. Further the re-colonisation potential of the cuttings pile should be considered.

The biological analyses should concentrate on bottom fauna structure in the samples taken at the pile and in adjacent areas. The sampling and analysis methods should be according to national regulations /6/ or similar OSPAR guidelines. This will also facilitate comparison of the conditions of the pile with that further out and at reference sites. In cases where the fauna at the surface of the pile is very poor, some of the indices listed in Appendix 5 (Shannon-Wiener and Hurlbert diversity) will be meaningless or impossible to calculate. The principles of fauna description should still be the same as that further away from the pile.

Comparison of the biological conditions at the pile surface and adjacent areas with that derived from relevant monitoring surveys should be done to assess the quality of the pile as substrate for a seabed fauna, and the degree of re-colonisation of animals at and around the pile. Such comparison should be made on basis of the univariate parameters, as well as on a range of routine statistical assessments. An overview of relevant statistical techniques and their application on seabed communities can be found in Gray et al. /8/.

5 Hydrocarbon leaching rate assessment and persistence of contaminants

The leaching rate of hydrocarbons is a function of the specific chemical's physical/chemical characteristics, the type of cutting pile or sediments and the hydrology in the area. Leaching of hydrocarbons from deposited matter to the pore water will normally be expressed as a function of the chemical's Log K_{OC} or organic carbon – water partitioning coefficient. Further leaching to the surrounding environment will depend on the diffusion of water between pore-water and surrounding waters, the migration of particles from the sediments to the open water, the biological activity in the bottom sediments, and oxygen availability. Most of these processes are poorly understood, and the majority of work performed on hydrocarbon leaching has been done in laboratories, not in the field /9/. Estimates of hydrocarbon leaching to the environment may be done using laboratory tests (batch-tests, column or flow-over tests), or by field monitoring (passive samplers, water and sediment analyses). Both methods have limitations, as laboratory tests often overestimate the leaching due to exaggerated exposure, while field monitoring often is limited to poor detection limits and reduced sensitivity towards the relevant contaminants.

5.1 Laboratory tests

Batch test

The easiest method to evaluate leaching of components from bottom sediments is the batch/serial batch test, where sediments are shaken for a given period of time to obtain equilibrium with the surrounding water (simulated pore water). The quantity of leached THC may conservatively estimate the amount of material available in the pore water of the sediments. No estimations may be given however of the amount of material leaching to the surrounding water, unless diffusion rates and reflux rates for the bottom sediments are known.

Flow over test

A flow-over test is where bottom sediments are exposed to flowing surface water, and the overlying water is analysed for THC. This is probably the best laboratory test to simulate the real conditions in the sea, given that a representative sediment is used for the experiments, and that the flow-rate of the overlying water is representative of the real conditions. This may also be done in combination with passive samplers (cf. 5.2).

5.2 Field measurements

The concentrations of THC in the surrounding waters are expected to be of a magnitude not normally detectable using conventional water sampling. Field measurements are therefore best performed using active or passive samplers (SPMDs, SPE extraction discs, PU foam, active pumps with suitable concentration material etc.) capable of concentrating the relevant THC from the surrounding water.

5.3 Combined methods

An estimation of the leaching rate of hydrocarbons from cutting piles is best performed by a combination of laboratory test and field measurements. Laboratory testing estimating the potential concentration of THC in pore water and/or migrating to the surrounding waters, and correlation/verification of the measured leachate using *in situ* methods.

In situations where the THC is located only in deeper sediment layers (>5 cm), the diffusion of contaminated water to the surface will be of less concern, and bio-turbation and re-suspension of deeper sediments will be more important factors to consider. In these cases other approaches are necessary and these should be evaluated on a case to case basis.

Measurements of changes in THC concentrations in different layers of sediments are not applicable to estimate leaching, as it is impossible to discern biodegradation from leaching properties.

5.4 Persistence of contaminants

Water depth and oceanographic conditions as ocean currents will influence on the formation of a cuttings pile but also on the erosion/degradation of the pile. UKOOA has concluded that for fields located at water depth of more than 70m wave action will generally not influence on the cuttings pile. Also the technical discharge arrangement may influence significantly in the formation of a cuttings pile, its extent and volume. These factors will be important in the evaluation of persistence of contaminated area (cf. section 6).

6 Application of results

The UKOOA R&D JIP concluded that hydrocarbons are prime contaminant in drill cuttings piles and will be the deciding management factor for most piles. The term environmental significance will thus depend on the level of hydrocarbon contamination and to which degree this contamination leach to the surrounding environment and the persistence of the contamination.
Based on this finding they have defined environmental significance/insignificance as:

Environmental Significance: If rate of loss of hydrocarbons > 100 Te/year at a particular site
Environmental Insignificance: If rate of loss of hydrocarbons < 10 Te/ year at a particular site & Hydrocarbons footprint over time at 50 mg/ kg < 500km^2

If a site has a persistence of less than 500 km^{2}years, then it is:

- virtually free of any hydrocarbons e.g. WBM;
- of small areal extent; or,
- recovering and able to be demonstrated as such within period of tenure of the operator.

Should persistence be greater than 500 km^{2}years then timely demonstration of recovery is the concern rather than impact as such

These criteria for environmental significance are illustrated and presented in Figure 7.

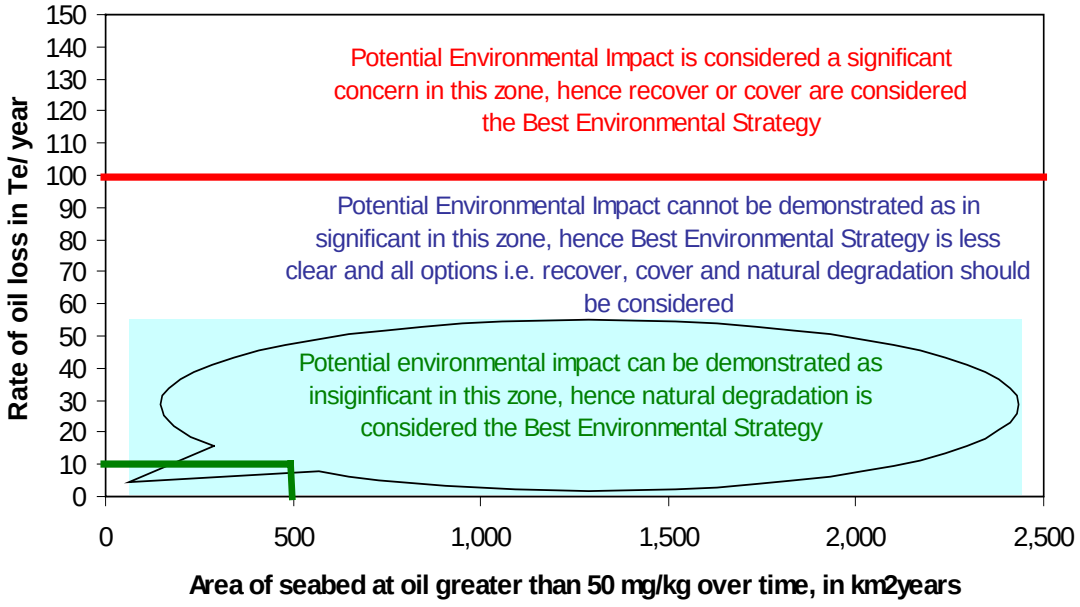

Figure 7. Criteria for environmental significance /2/.

The guidelines are developed to ensure information is gathered to an extent and at a level of detail that makes it possible to evaluate the environmental risk associated with drill cuttings residues at a site. The guidelines are designed as to document the present situation and to give indications about degradation and time trends. Based on such information, those responsible for the field should be in the position to establish a plan for a sound cuttings piles management as an integrated part of the overall cessation planning (see Figure 8).

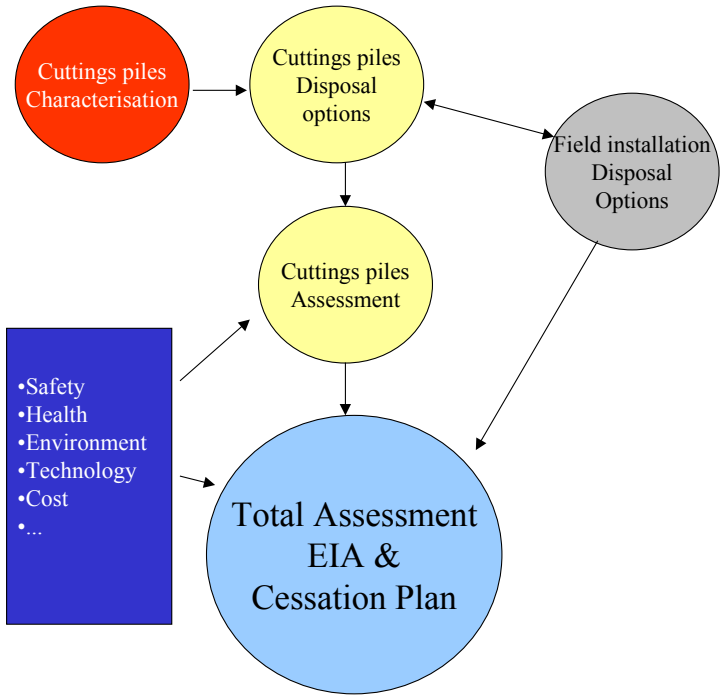

Figure 8. Cuttings piles management process as part of the overall cessation plan development.

References

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/2/ UKOOA Drill Cuttings Initiative. Final Report. December 2001.

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Appendix 1. Relevant in situ investigation and sampling techniques.

A1.1 Recommended sampling techniques.

Core sampling of the cuttings pile serves two purposes, which may demand shifting between alternative types of corers. Sampling of pile surface material (e.g. upper 0.5 – 1 m) for analyses related to biodegradation and leaching of contaminants should be done by use of a lighter gravity corer (e.g. a Niemistö type /15/) which takes samples without disturbing the sediment surface. If a box corer is used for fauna sampling (cf. below) subsamples may be taken from the box on deck by a hand held corer for surface related analyses. Further guidelines on surface sediment sampling can be found in Norsk Standard NS 9422.

Sampling of deeper layers of the pile will normally demand heavier gravity corers or alternative corer technology. In some situations core sampling may not be feasible. Occurrence of larger objects and cement in the pile may prevent coring altogether. Also firm, claylike strata in the pile may cause plugging of the corer and prevent material below to enter the corer. 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, e.g. CPT.

Samples for analysis of bottom fauna should be taken by use of a grab or a box corer as recommended by SFT /4/ for the regional environmental monitoring. Heavy duty offshore grabs, such as e.g. the van Veen grab or similar are best suited for sampling sandy and mixed sediments, whereas box corers are most suited in softer sediments and especially when larger undisturbed cores are wanted. It is important that the gear is fully closed when lifted from the bottom to avoid sediment surface disturbance and loss of material. Sampling area should as a minimum be 0.1 m^2. Further details on grab sampling and sample acceptance criteria may be found in Norsk Standard 9423.

A brief technical description of the most relevant sampling and in situ testing techniques to be used in a cuttings pile survey is given below. The description below relates to state-of-the-art sampling and testing techniques which can be operated from cranes or winches from medium size vessels. The development within this field may in the future produce better techniques for sampling in gravelly sediments, through very thick deposits, and underneath the platform deck.

Vibrocorer

The vibrocorer is a method of driving a sample tube into the seabed by vibratory means. Typical systems comprise a steel core barrel of between 75mm and 100mm in diameter and 3 - 6m in length. 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, 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.

The 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 under the combination of the vibratory effect and the weight of the motor. 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 an onshore laboratory.

System enhancements that are available include higher frequency motors to improve penetration in sands and percussion attachments, usually comprising a spring and reciprocating weight arrangement between the motor and core barrel, to improve penetration in stiff clay.

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

Disadvantages
- Penetration may be limited in dense cohesionless strata or very stiff clays and thus fail to recover samples of critical strata.
- 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 with the effect that subsequent laboratory tests for parameters such as shear strength and consolidation characteristics may produce unrepresentatively low values.
- For some vessels the equipment can prove cumbersome to handle particularly for the longer barreled models. For example some "6 metre" vibrocorers have a total height of around 7.5 metres and a maximum base width of 5 metres.

Gravity corers

The standard gravity corer normally comprises a core barrel, liner and cutting shoe, very similar to those used with vibrocorers. On top of the core barrel is a single large weight or a series of adjustable smaller weights usually totaling between 0.5 tons and 1.0 tons. They are deployed on a single steel lifting cable and penetration is achieved by allowing the unit to free fall the last 5 to 10 metres to the seabed. Surface sediment corers (e.g. Niemistö /15/) are generally somewhat smaller and lighter than this. They should be completely open during deployment so as to hit the sediment with a very modest bow wave to catch the boundary layer.

The "stationary piston corer" (or Kullenberg-type corer) operates with a 'trip-release' mechanism and 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 thus resulting in 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 to 6 m in soft sediments (note that larger gravity corers exist which can take cores of 35 to 40 m length. These require larger vessels for operation).

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

Grab sampler

The grab sampler is, in simple terms, an articulated bucket which closes when it comes into contact with the seabed and in so doing collects a sample of the surface deposits. These samplers can range in enclosed volume from a few liters to a cubic metre and closure is activated by a simple trip mechanism or by hydraulics in the case of 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 in the case of larger hydraulic units, which however 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 finer fraction of recovered sample thus rendering particle size distribution analysis unreliable.

Seabed rock corers

There are a variety of these available on the market ranging in size from around 1 tonne to 13 tonnes and theoretically capable of taking cores with diameters ranging from 25mm to 150mm, to penetrations of up to 9 metres. Most incorporate a rotary drive mechanism and diamond or tungsten carbide impregnated drilling bits plus an inner core barrel. Their main advantage is to be able to take cores of rock outcropping at or near seabed without recourse to a floating or fixed drilling platform. Their primary disadvantage is the variability in performance and recovery. The 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, means 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 purposes, it is designed to push a metal box about 0.5 metres into the seabed and, on retraction, seal in the sample by means of a blade-like door which closes beneath the box. Sample volumes are typically in the range 10 litres to 50 litres.

Its main application is in the retrieval of good quality block samples of soft clay in a manner that also permits inspection of a relatively undisturbed section of the seabed surface. Its 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. The 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 is taking place. The Selcore is available in different sizes, ranging from 500 kg to 2000 kg.

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

Disadvantages
- Initially there were some problems with controlling the energy from the motor, resulting in overpenetration or severely hammering into bedrock. Later versions may have improved this.
- Like for other coring equipments, the penetration in soft sediments may be larger than the recovery.
- The system requires a minimum differential pressure to operate, i.e. minimum120 m water depth. In less than 120 m a power pack is required.

Cone/Piezo Cone Penetration Test (CPT/PCPT or CPTU) and envirocones
Cone Penetration Testing involves the measurement of the resistance to the controlled penetration into the ground of a steel rod with a conical tip. Standard electrical cone penetrometres incorporate internal load cells that measure resistance on 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 the penetration of the cone. Standard cones have a cross sectional area of 1000mm^2 or 1500 mm^2 although some new systems are using cones with an equivalent area of 100 mm^2. The testing equipment and operation procedures are described in Lunne et al., 1997.

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 of 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 correlation.

Advantages
- Usually guarantees greater penetration.
- Provides a complete stratigraphic profile (continuous measurement)
- Gives data in real time allowing almost immediate interpretation of ground conditions.
- Can reduce the amount of time-consuming laboratory testing.
- Provides the only reliable method of 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 on degree of contamination (e.g. el. resistivity and fluorescense probes)

Disadvantages
- Weight, although ligth weigth systemes are available, typically 5 tones to 10 tones units are required to ensure sufficient reaction force to achieve the desired penetration in dense sands/stiff clays
- Cost; the technical complexity and precision engineering involved in many of the components inevitably makes it a more highly priced item of equipment and 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 have been developed for geotechnical drilling that can be used in the survey of medium to large drill cuttings piles. A seabed frame is required to guide the drill pipe at the seabed, and to provide necessary reaction force when pushing the sample tube or a probe into the sediment. The testing and sampling is performed inside and ahead of the drillbit into the bottom of the borehole.

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

Disadvantages
- Requires large dedicated drilling vessel, most commonly DP operated
- Larger mobilisation costs and higher dayrates
- Operation restrictions to distance from the platform

A1.2 Geophysical testing techniques

The table below describes three *in situ* geophysical techniques that can be used to survey the area around an offshore installation to map the extent and possibly the thickness of a drill cuttings pile. The systems are usually deployed from surface vessels, but can also be deployed from ROVs or similar, which would be the case around offshore structures.

Type	Deployment	Data obtained	Penetration depth and resolution
Multibeam echosounder (High frequency domain)	Surface vessel or ROV	Detailed map of the seabed topography. Compared to similar survey data prior to drilling can provide	Surface mapping only

		estimates of drill cuttings volume (Note, seabed settlements should be evaluated)	
Sidescan sonar	Surface vessel or ROV	Reflective image of the seafloor. Can provide information on seafloor topography and seafloor character	Surface mapping only
Subbottom profiling (Echosounder technique, low frequency domain)	From surface vessel or ROV	Echosounding profile of the upper seabed sediments. To be interpreted with respect to layering and possibly sediment type.	Penetration and resolution depends on the frequency range used. Penetration > 20 m, resolution down to 0.1 m

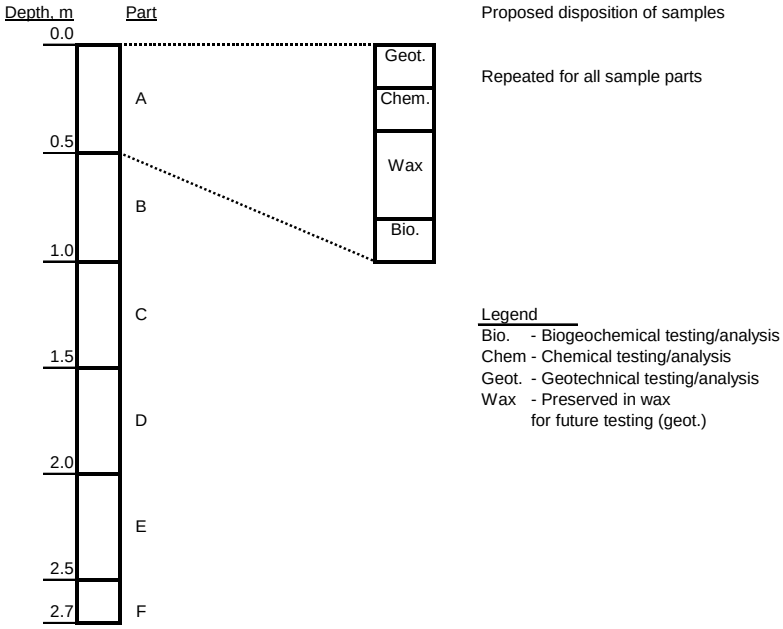
Appendix 2. Handling and preservation of samples.

A2.1 Disposition of samples

Two types of core samples are recommended to cover the geotechnical, chemical and biogeochemical characterisation of the pile. The reason is that most equipment designed to take deep cores will disturb the boundary layer at the surface of the pile, where the most intensive biochemical activity and the exchange of substances with the overlying water are expected to occur.

A2.1.1 Deep core samples

Figure A2.1 below proposes a procedure for sectioning and disposition into sample parts for further testing and preservation of a uniform, non stratified deep core sample obtained with gravity corer or vibrocorer. Procedures for preservation and sealing of sample parts for the various chemical, biological and geotechnical tests are outlined in Annex A2.2.



Notes:

- The example can be a gravity core or vibrocore sample of 2.7 m length
- The sample should be cut into smaller sample parts for further disposal and testing
- The numbering of the samples shall identify the sample location, and the parts should be numberd alphabetically, starting with Part A at top.
  In the example above the sample is cut into 50 cm long sample parts. Distinct layering in the sample must be reflected in the disposition, so that material from two layers is not mixed together in the same part
- Each sample part can be used for various tests. The identificaton of each test will then be: Sample XX-part A-Test 1, or simply Test XX-A-1
- The sample parts can be tested offshore, or preserved for further analyses onshore.

Figure A2.1. Proposed plan for sectioning and disposition of sample parts from deep core samples.

In case of a stratified core sample, which is the most typical structure of a pile sample, one should ensure that each apparent stratum is treated as an individual sample part (cf chapter A2.2)

A2.1.2. Shallow core samples

Figure A2.2 proposes a procedure for splitting and testing of a shallow sample obtained from the upper 0.50 m of the cuttings pile or seabed sediments. The purpose of the sample is to perform chemical and biological tests of the active zone of the seabed. The figure indicates testing of the samples at increasing intervals with depth. More detailed splitting and testing may be considered. Figure A.2.3. shows the principles of electrode measurements of pH, Eh and sulfide in each part of the core (cf Annex A4.2 for details).

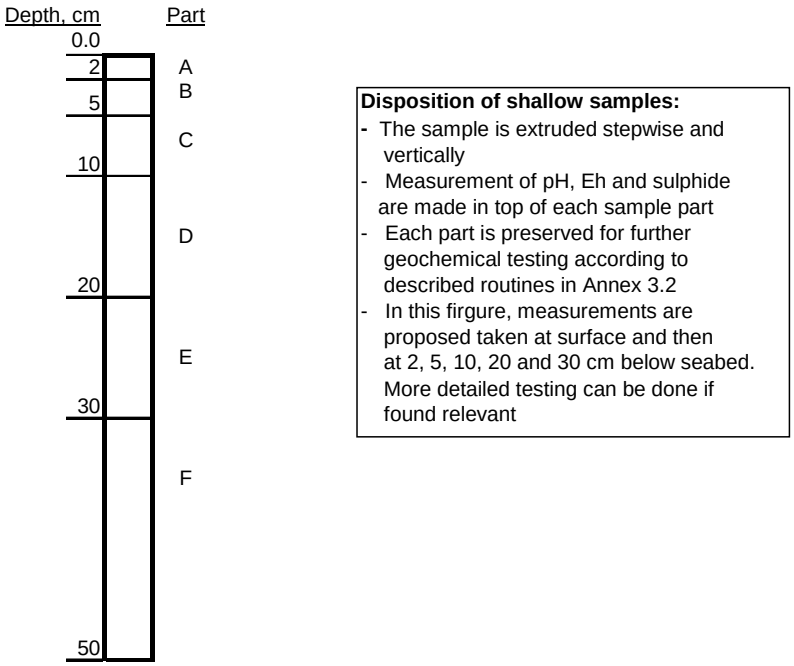


Figure A2.2. Proposed plan for sectioning and disposition of sample parts from shallow core samples.

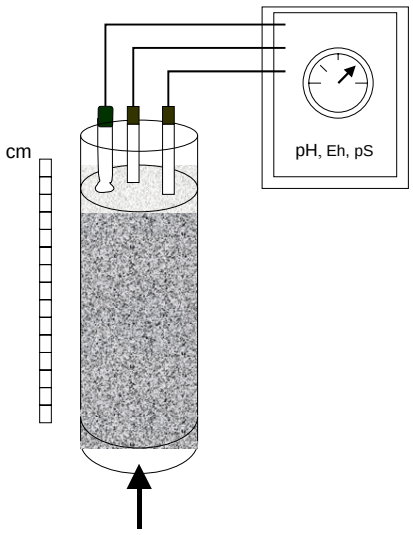


Figure A2.3. Diagram showing the measurements of pH, Eh and sulfide in upper parts of the shallow core.

A2.2 Treatment of core samples

Core samples should preferably be sectioned immediately after retrieval on deck, and the various depth sections (parts) secured for further treatment. Sectioning is generally performed by piston-pushing the core upwards from the bottom and slicing the top parts off one by one. Alternatively (especially for long core samples) the corer itself is cut horizontally into parts with the material inside and secured for further analysis. One may also cut longer cores in half vertically to obtain a complete overview of any stratification prior to subsampling and electrode measurements, but this procedure may destroy the samples for certain geotechnical tests later. When the corer is cut with the sample within, one may consider freezing the corer prior to cutting to preserve its structure.

Measurements of pH, Eh and sulfide (cf Annex A4.2), and visual description of the core should be done in connection to the sectioning and before any disturbance of the depth section in question occurs. Also subsamples for wax preparation must be secured while the sediment structure is intact.
The sectioning program should take into account any distinct layers or strata in the core, and should ensure that each stratum deemed to be important is sampled individually. Inclusion of several distinct strata in one sample should be avoided. If a core is homogenous in appearance it may be sectioned into standardised parts according to figures A2.1 and A2.2 for further analysis.

Subsamples for chemical analysis are withdrawn either after homogenization of the complete sample part, or from a defined sub-stratum of the part. The procedure of subsampling must be described in sufficient detail to enable tracing of the result back to its exact origin in the core. All samples should afterwards be appropriately contained and stored for further analysis.
Visual description of the core should comprise:

- sample length,
- visible strata and length of these,
- general appearance (sandy, muddy, liquid phase, solid objects, larger fauna)
- colour (with reference to Munsell Soil Colour Chart System, Munsell Colour, Maryland, USA)
- smell (e.g. oil, hydrogen sulfide).

Samples for analysis of TOC, metals, and biodegradation should be stored in clean (pre-washed) plastic bags or plastic containers. Non-metal or stainless steel utensils shall be used to handle these samples.

Samples for analysis of organic compounds should be stored separately in solvent rinsed pre-incinerated glass jars supplied with solvent rinsed aluminium foil lined lids. Alternately these samples may be wrapped directly in solvent rinsed aluminium foil, which again are stored in plastic bags. Stainless steel and glass utensils shall be used to handle these samples.

Separate samples for metals and organic compound analysis are necessary primarily if only trace concentrations are expected. At the levels one may expect to find in the cuttings material the samples preserved for TOC and metals may also be used for analysis of hydrocarbons and other organic base fluids. The analytical flow diagram in Annex 5 is based on a common sample for the chemical parameters.

A2.3 Treatment of grab samples

Grab samples for fauna analysis should be treated on deck according to SFT (1999a) or the Norsk Standard NS-9423. The sample is transferred from the grab to a hopper table or large container and very gently mixed with running seawater. The overflow of seawater-sediment slurry is led through a sieve with 1mm round holes immersed in another container. Sieving must be very gentle to avoid damage to delicate organisms. A separate 5 mm sieve may be installed in front of the 1 mm sieve to prevent larger objects from damaging the final sample. Figure A3.4 shows the principles of the sieving arrangement. The material retained on the sieve (or both sieves if two are used) is transferred to glass or plastic jars and preserved in 10-20 % formalin-seawater solution (4.5 – 7 % formaldehyde) neutralized by use of borax, hexamine or marble chips. All samples shall be appropriately marked for later identification. The samples may be stored at ambient temperature.

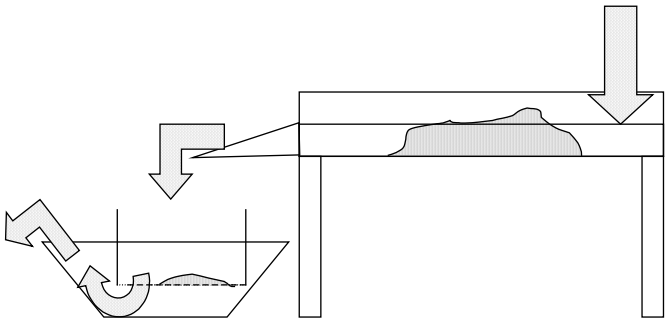


Figure A2.4. Diagram of sieving procedure for sediment macrofauna samples.

Appendix 3. Relevant geotechnical analyses.

The geotechnical testing can be divided into classification testing (index testing) and advanced testing. It is likely that classification testing is most relevant for this type of survey. However, accurate evaluation of stability and settlement of a drill cuttings pile will require advanced laboratory testing including triaxial tests and consolidation tests (oedometer).

A3.1 Classification testing

Sediment description and classification

The sediment description and classification should be made in accordance with a well established classification system, such as:

- The Unified Soil Classification System 1953.
- BS 5930: 41-42, British Standard, 1981.
- ASTM D 2487 2487-93, ASTM, 1995.
- Norwegian Geotechnical Society; guidelines and recommendations for presentation of geotechnical soil investigations, NGF, 1982.

The latest version of the above documents should be used. Prior to start of laboratory testing, the classification system to be used should be stated. A detailed description of the material in each individual core sample retrieved should be made (cf Chapter A3.2).

Total unit weight, γ_{tot}

Density, ρ, of a soil specimen is determined by measuring its diameter and length and then weighing it. Unit weight, γ, is equal to $\rho \cdot g$. Unit weight is given in kN/m^3 and density in g/cm^3. This parameter can most accurately be determined on undisturbed samples. Estimates for total unit weight can also be made on undisturbed samples (sands) using a mould, but will usually be less accurate since the *in situ* density (or porosity) can not be reproduced. Relevant standard is NS 8011.

Specific gravity, γ_s

Density of solid particles, ρ_s, is measured by means of a density bottle according to standard soil testing procedures (NS 8012). Unit weight of solid particles, γ_s, is equal to $\rho_s \cdot g$. Relevant standard is NS 8012.

Water content

Water content (w) is the mass of water in the sample expressed as a percentage of the mass of solids. It is found by weighing a representative part of the sample before and after 17-20 hours of oven drying at approximately 110°C. (Note that water content will also be an output from the routine chemical analysis (figure A4.1)). Relevant standard is NS 8013.

Grain size distribution

A grain size analysis gives the composition of a sediment in terms of amount of particles for selected diameters. The results are presented as plot of percent finer by weight versus particle diameter in mm. The grain size distribution can be determined by dry sieving for sandy sediments, wet sieving for sand with some fines content (fines = silt + clay particles) and by falling drop or hydrometer analysis for silt and clayey sediments. Combination of the

methods may also be required for well-graded sediments. The grain size distribution as a basic parameter that also can be correlated to other sediment parameters, e.g. the sediment permeability.

Atterberg limits tests
The plastic limit and the liquid limit tests are the most common used tests of the Atterberg limits. Liquid limit (w_L) and plastic limit (w_P) are the highest and lowest water contents respectively, at which the remoulded sediment material is in a plastic state. The test is only applicable for clayey sediments. Standard methods described in the Norsk Standard NS 8002 and NS 8003 are used to determine w_L and w_P.

Index undrained shear strength, s_u,
The index undrained shear strength can be determined using pocket pen, torevane, fallcone, and laboratory inspection vane. The parameter is only relevant for clay type material. Relevant standards are NS 8015 for the fallcone test and BS 1377 for the torevane and the laboratory inspection vane. Reference must be made to the operation sheets from manufacturer for pocket pen equipment.

The sensitivity, S_t, of a sediment sample is defined as the ratio of undrained shear strength of intact material ($s_{u,int}$) divided by the undrained shear strength of the remoulded material ($s_{u,rem}$),
$S_t = (s_{u,int})/(s_{u,rem})$.

Density evaluation
The sediment relative density or porosity can be determined from laboratory tests, or can be evaluated from CPT results. It should be kept in mind that correlations between cone resistance ,q_t, and relative density is based on tests on pure sand, and may not be directly applicable for drill cuttings deposits.

Evaluation of particle cementation
Cementation and chemical bonding between particles in a sandy sediment cannot be tested with standard geotechnical tests in the laboratory. Hence, the description must be a subjective evaluation of the samples, and may be limited to describing the sediments as without chemical bonding, or with low/moderate/high chemical bonding between particles.

Other relevant standards for the individual tests are given by NORSOK (1996).

A3.2 Advanced testing

Triaxial testing (strength properties)
The triaxial test is carried out in order to measure the stress-strain behaviour and the shear strength parameters of a soil specimen under controlled stress conditions. The test is performed on a cylindrical sediment specimen, which is enclosed in a rubber membrane and placed inside a pressure chamber called a triaxial cell. The test can be performed on specimens cut directly from the samples or on specimens trimmed down to a smaller diameter. An isotropic stress is applied to the specimen through the chamber pressure. In addition to the chamber pressure the specimen is loaded axially by a piston passing through the top of the cell. After consolidation, the specimens sheared to failure (large axial strains) in compression (or in extension). Reference may be made to ETC5-F1.97.

Direct Simple Shear test, DSS (strength properties)
The DSS test is performed in order to measure the shear stress-shear strain behaviour of the sediment specimen under controlled stress conditions. The test is performed on cylindrical sediment samples with cross-section area of typically 20, 35 or 50 cm^2 and height of 16 to 20 mm. The sample is placed within a reinforced rubber membrane that prevents radial deformation, but allows the sample to deform in simple shear.

The sample is consolidated vertically to a predetermined effective stress (e.g. the *in situ* vertical effective stress at the sample depth), and then sheared to failure horizontally. Description of the test is given by Bjerrum and Landva, 1966 and Andresen et.al, 1979.

Oedometer consolidation tests (settlement properties)
The oedometer tests is performed to determine the compressibility (constrained modulus) and coefficient of consolidation of the specimen tested. The specimen is mounted inside a rigid steel oedometer ring that allows for vertical compression but no lateral strain. The specimen is then loaded axially, and the relation between axial load and axial strain is obtained. The tests can either be performed as an Incremental Loaded (IL) test (Norsk Standard 8017), or as a Constant Rate of Strain Consolidation (CRSC) tests (Norsk Standard 8018).

Appendix 4. Relevant chemical and biogeochemical analyses.

A4.1 Analytical approach

The chemical analyses to be carried out cover a wide range of parameters and concentration levels. Some of the analyses (bulk parameters) are performed to distinguish between pile material and seabed sediments, others may be performed to describe chemical composition especially with respect to selected hazardous substances at relatively low levels. The properties of inorganic and organic compounds or compound groups to be determined will vary widely with respect to volatility, extractability, chromatographibility etc.

Some of the analyses are done on a specific fraction of the sample (e.g. for metals on material finer than 0.5 mm). In the present context the focus is on the total content of the contaminants in the cuttings material. Hence the analytical results should be used to calculate the concentrations in the total cuttings material, not only in the fraction analysed.

The biogeochemical analyses are recommended to assess the degree of degradation/degradability of the cuttings pile material.

A4.2 Chemical analytical procedures

The analytical approach as shown in fig. A4.1 is designed to allow all analyses to be performed after freeze drying of wet samples. This process has been chosen, since it provides a gentle way for the removal of water, even if some of the more volatile organic components (especially the lower boiling fraction of diesel oil) will be influenced.

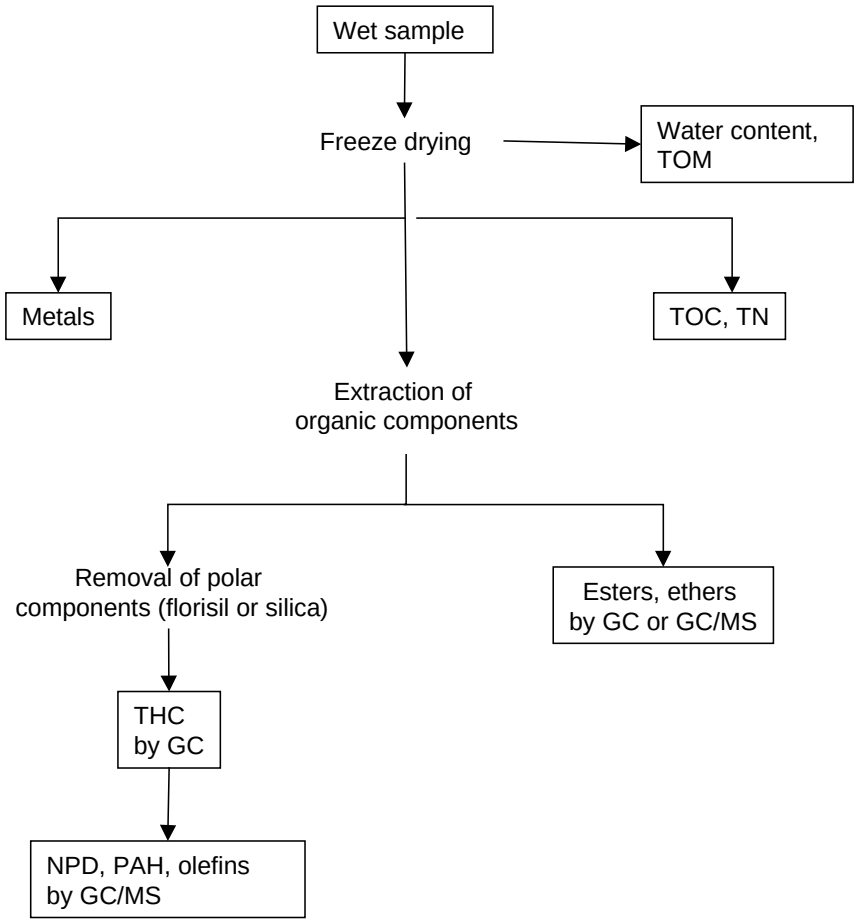
Alternatively, a more precise procedure would be to extract organic components directly from the wet samples (using methanol followed by a non-polar solvent for the extraction and subsequent workup). Such a procedure is however more demanding and time consuming. Since the main purpose of the analyses is to decribe the conditions of the piles with contaminant concentrations in the $^{o}/_{o}$ to $^{o}/_{oo}$ range, it is expected that the freeze drying procedure will provide results of sufficient accuracy.

The analytical procedures outlined below are presented in short versions only, mainly concentrating on principles of the analytical processes, thus leaving the individual laboratories flexibility to apply their own specific routines. As a main rule, any analytical procedure may be chosen provided its performance has been documented by analysing Certified Reference Materials with results within one standard deviation of the certified values. In cases where certified reference materials are not available (i.e. THC, alkyldecalins, esters, ethers etc.) the laboratory should demonstrate the validity of the method chosen by documenting it's performance based on house standards, spiked samples etc.
Limits of detection and quantification of the analytical methods used should be documented according to ACS Committee on Environmental Improvement (1980).

The recommended analytical procedures given below correspond to those required for the environmental monitoring surveys around Norwegian offshore fields /4/, and which have been applied in this context for more than 10 years.

A4.2.1 Freeze Drying/Water Content

Wet sediment samples are weighed into a glass jar and freeze dried to constant weight. The weight difference is calculated and the loss recorded as water content in %.



TOM: Total Organic Matter
TOC/TN: Total Organic Carbon and Total Nitrogen
THC: Total Hydrocarbon Content
NPDs: Naphthalene, Phenanthrene, Dibenzothiophene and their C_1 -, C_2 - and C_3 - alkylated homologues
PAH: Polycyclic Aromatic Hydrocarbons (EPA's list of 16 compounds)
Olefins, Esters, Ethers: dependent on which synthetic drilling fluids have been discharged
Metals: As, **Ba**, **Cd**, Co, Cr, **Cu**, Fe, Ni, **Pb**, Zn, **Hg**, Mn, Sr, V

Figure A4.1 Flow diagram of chemical analysis of cuttings material. Priority parameters in bold.

A4.2.2 TOM

Total organic matter is analysed as weight loss of the dry sample after incineration at a controlled temperature of about 500°C. Pretreatment with hydrochloric acid to remove inorganic carbon (i.e. carbonate) is recommended.

A4.2.3 TOC and TN

The analysis of carbon and nitrogen is performed after high-temperature (1800^{o}C) combustion of crushed, freeze dried material in a CHN-elemental analyser. After determination of total carbon (TC) and nitrogen (TN) the carbon determination is repeated after treatment with approximately 1 n HCl for removal of inorganic components from the carbon pool.

A4.2.4 Metals

The freeze dried material is homogenized and extracted by use of nitric acid for the analyses of all metals apart from Hg according to Norsk Standard NS 4770 and by use of ICP-AES. Analysis of Hg is performed by the cold vapour technique acording to Norsk Standard NS-EN 1483.

A4.2.5 Organic Components

Extraction

The sediment is extracted after freeze drying with dichloromethane either in a Soxhlet apparatus over night, with ultrasonic treatment of sufficient energy (3 times) or by the use of saponification with methanol/NaOH followed by extraction with dichloromethane.

In case of further detailed analyses for single components like NPDs or PAH etc., appropriate internal standards are added to the samples prior to extraction such as perdeuterated biphenyl, phenanthrene, pyrene, chrysene and perylene. Other suitable internal standards may be added for the analysis of olefins, ethers and esters depending on the nature of the synthetic drilling fluids used.

Esters and ethers are analysed directly by high resolution gas chromatography. For all other organic analyses (various hydrocarbons) the extract is evaporated carefully (avoid loss of volatile components) almost to dryness, the solvent is changed to n-hexane and then chromatographed on florisil or silica (e.g. by using bond-elut or equivalent cartridges) to remove polar components.
The extracts are concentrated/diluted to a suitable volume depending on the concentration of compounds or compound groups (f. ex. 1 – 20 ml) prior to instrumental analyses.

THC

THC is determined by GC/FID with rapid temperature programming. The total response is quantified (area of single peaks plus unresolved envelope) in the range of C_{12} to C_{35} using a standard reference oil (Heavy Diesel Fuel, HDF 200) as external standard.

NPDs, PAHs, olefins
These compounds may be determined by GC/MS in the single ion monitoring mode after proper calibration of the instrument using the same treated extract as used for the THC analysis.

Esters, ethers
These synthetic drilling fluids may be analysed by GC/FID using appropriate internal or external standards. Procedural details should be harmonised with those used in the regular environmental monitoring surveys from the same field. This will facilitate data comparison.

A4.3 Measurement of pH, redox potential (Eh), and sulfide

Electrode measurements may provide basic information on superior chemical parameters interacting with the biological environment. Low-cost, "on-line" assessment of environmental condition is the benefit. Electrode drift and strenuous field conditions are the main obstacles. Trained personnel are required to perform sectioning and measurements during field surveys.

Numerous electrodes and instrument configurations are available commercially and detailed instructions on calibration procedures and measurements are supplied with the instrument. Further details on set-up, equipment and procedures for determination of pH and Eh in marine sediment samples, can be found in Hansen et al. /10/ and Norsk Standard NS-9410. A few principles are given below. Redox potentials should be measured on a platinum electrode. The sulfide ion activity should be measured on a silver-silversulfide (Ag │AgS) electrode. If a glass-combination-electrode is used for pH-determination, the internal reference electrode may be used as a common reference electrode. Alternatively standard Ag │AgCl with a KCl filling solution is a recommended reference electrode for the two metal electrodes. ISFET (Ion Specific Field Effect Transistor) type pH-sensors are more robust than glass-electrodes and the precision is appropriate for field measurements.

High precision measurements are not required. The pH electrode should be calibrated in standard buffers of pH 4 and 7. The metal electrodes need no calibration, but the half-cell potential of the reference electrode must be known and added to the recorded cell-potential. Precision should be within ±0,1 pH-units, ±1 mV for sulfide-electrode (larger in samples beyond sulfide detection limits) and ±20 mV for the redox potential.

Measurements are performed during core sectioning by insertion of the electrodes into the top of the cores (figure A2.3). pH- and mV-values are recorded as soon as a stable reading of pH is obtained, usually within 1-2 minutes. Potentials on both redox and sulfide electrodes may drift when S^{2-} ion activities are low. Values recorded during drift larger than 0,2 mV/s should be rejected or indicated in the report. pH-electrodes respond slowly when transferred from buffers with low ionic strength to saline pore water samples. Therefore, between measurements, electrodes should only be allowed contact (rinsing and storage) in seawater or a 3% NaCl solution.

Sediment cores may be stored for a few hours prior to the measurements. They should be protected from sunlight and kept at temperatures as close as possible to *in situ* temperature. During core processing, however, samples must be measured within 5 minutes after exposure of each core segment to atmospheric oxygen.

Electrode measurements may also be performed *in situ* by attachment of appropriately designed electrodes, potentiometers and a data aquisition unit on the sampling equipment lowered into the seabed (e.g. the CPT unit). They may also be done on grab samples by inserting the standard electrode assembly into the sediment through the inspection lid before processing the sample.

The report should contain pH-values and the mV-signals recorded on the metal electrodes corrected by addition of the potential of the applied reference electrode. The corrected mV value from the Pt-electrode corresponds to the redox potential (E_h). The potential recorded on the sulphide electrode is proportional to the sulphide ion activity. If required, the concentration of hydrogen sulphide may be calculated from the pH and the recorded potential.

A4.4 Leaching tests

Leaching tests are performed to assess the potential for mobilisation of contaminants from cuttings material, either the present leaching from the pile surface or the potential for leaching from buried material if later exposed to the water. These tests should be performed on wet material. The sample is agitated with water (leaching solution). After agitation, filtration or centrifugation is used to separate water (leachate) and solid material. If sequential leaching test is performed the solid material is agitated together with a new portion of leaching solution.

Relevant standards describing leaching tests are NEN 7349 and NVN 7350. Recommendations regarding the use of these standards are given in SFT /11/. These standards are designed for modelling leaching to ground water, and therefore use fresh water as leaching solution. To produce data relevant for the mobility of contaminants to seawater, water with the same salinity and pH as ambient seawater should be used as leaching solution. This could be obtained by using either seawater sampled close to the investigation site or by preparing artificial seawater solution from freshwater and NaCl, and adjusting pH with NaOH.

The leachate solution(s) resulting from the tests should be analysed for the compounds found in high concentrations in the pile material.

If a treatment option for the cuttings pile material is deposition on land, leaching tests with fresh water as leaching solution should be carried out. This will produce data relevant for the leaching of contaminants to rainwater or groundwater. The pH of the leaching solution must reflect the expected acidity of the rainwater at actual deposition sites.

Relevant standards for the tests are NEN 7349 and NVN 7350.

Appendix 5. Relevant biological analyses.

A5.1 Analysis of soft bottom macrofauna

The analytical principle is the same as required by SFT /4/ for analysis of macrofauna (animals larger than 1 mm) in offshore sediment samples. The analysis is in accordance to Norsk Standard NS-9423. Valuable information on the occurrence and abundance of larger animals at the surface of the pile may be extracted from the ROV recordings.

Animals of the groups Porifera, Harpacticida, and Nematoda, pelagic animals such as copepods and mysids, and fish caught in the samples may be identified, but they should be excluded from calculations of community indices and from any multivariate analysis of community similarities.

Solitary hydrozoans should be identified and included in the calculations, but not colonial forms. Some animal groups, e.g. Oligochaeta, Cnidaria, Solenogastres, and Phoronida need special preservation techniques and expertise for their identification. For the description purpose these groups may be separated into morphological forms only.

High densities of newly settled and juvenile individuals of benthic species may during summer dominate the macrofauna. Such juveniles should be identified, at least to higher taxonomic group, and counted. An assessment of the spatial distribution of the juveniles may give information regarding the substrate qualities of the pile surface. If this assessment is given priority, the sampling survey should be performed during the summer (June – August) when the settling of larvae to the seabed is most intense.

The following characteristics and indices should be calculated to describe the fauna structure at each sampling location:

- total number of species (or higher level group if species identification is impossible),
- number of individuals of each species (per m^2),
- total number of individuals (sum of all species per m^2),
- complete name lists of species found,
- diversity as Shannon-Wiener index (log_2 basis, Shannon and Weaver 1963 /12/),
- evenness as Pileou's "J" /13/,
- expected number of species per 100 individuals after Hurlbert /14/,
- a table of the 10 top dominant species per site.

It is recommended that the taxonomic resolution in species identification is the same as in the regional biological monitoring surveys /4/.

The calculations above and any statistical analyses should be run with and without dominating juveniles if they are among the 10 top dominating species.

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