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OPTIONS FOR TREATMENT AND DISPOSAL OF OIL-BASED MUD CUTTINGS IN THE CANADIAN ARCTIC

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SUMMARY

Dobrocky Seatech Ltd., with support from Technifluids and the Institute of Offshore Engineering, Heriot-Watt University, U.K. has prepared a report reviewing the treatment and disposal options, for use in the Canadian Arctic, for cuttings contaminated with oil-based drilling muds (OBM).

Routine solids control equipment, plus 24 additional treatment systems, were considered and the consequences of offshore disposal, onshore disposal, and incineration were evaluated for each. The emphasis of the report is on presenting information to assist in decision-making by operators and regulatory agencies. Background information on the physical environment, on the environmental effects of oil-contaminated cuttings, and on cuttings cleaning technology, was reviewed and used as a basis for developing matrices to enable operators to evaluate the engineering, environmental, and financial consequences when choosing a treatment system and method of disposal.

The major factors influencing the dispersion of cuttings discharged at an offshore location are wind and waves, currents, and sea ice. Wave action will have a significant influence in shallow waters but at depths of more than 20 m the effect is thought to be minor. Currents, especially in shallow waters and during open water conditions, will play a role in the dispersion of cuttings and associated fines, and in the resuspension and mixing of cuttings with bottom sediments. High levels of suspended sediment, associated with the Mackenzie River plume, may also provide a clean substrate for recolonization of areas contaminated with cuttings. The major effects of ice will be on transportation and logistic support, although scouring will have some influence on the dispersion of cuttings discharged in shallow waters.

Few data exist on the environmental effects of OBM cuttings discharged to the Arctic marine environment. Most of the information available is based on data collected in the North Sea fields. The seabed effects associated with these discharges has been described in terms of "zones of effect", which include complete burial near the discharge site, changing to organic enrichment and a gradual return to background conditions, at distances further away from the well site. The shape and extent of these zones is variable and largely depends on the current regime and the amount and type of cuttings discharged.

The toxicity of base oils and drilling muds has been assessed in terms of both acute and chronic toxicity. While aromatic compounds can play a significant role in the

toxicity of various oils to marine organisms, there is less evidence that cuttings contaminated with low toxicity base oil muds (LTM) will have a smaller overall biological impact than cuttings contaminated with diesel base oil muds. However, there has been some indication in the North Sea that benthic communities exposed to cuttings with diesel recover their normal diversity at a greater distance than those exposed to LTM cuttings. There also appears to be a correlation between benthic diversity and sediment naphthalene concentration. Recolonization of cuttings may be promoted by the use of LTM. Similarly, the potential for the induction of mixed function oxidase (MFO) in marine organisms is likely to be reduced by substitution of low-toxicity base oils for diesel. Weathering of oil from cuttings appears to be slow, with leaching rates of 1-2 $g/m^3/d$ being quoted for laboratory studies in low-energy environments. Rates of dispersion of oil should be higher in the nearshore areas of the Beaufort Sea. It was concluded that the overall effects on the environment of oiled cuttings in the Beaufort Sea and high Arctic, would be about the same, or less, than was reported for the North Sea.

Onshore disposal options include burial (sumps), land-spreading, and incineration. However, the remoteness of the Arctic can pose severe problems with regard to transportation and logistical considerations associated with shipping of cuttings to shore prior to onshore disposal, and a dedicated vessel will likely be required. Onshore drilling, and transport of cuttings, will be restricted during periods of freeze-up and spring thaw.

The effects of onshore disposal include seepage of the oil to nearby land or aquatic environments, and physical damage caused by equipment during construction or maintenance of the disposal site. Burial of oiled cuttings in the permafrost, below the active zone, may immobilize the material, particularly if the sump is properly constructed, and includes a lining of impermeable material. But, if burial occurs in the surface active layer, above the permafrost, the freeze-thaw cycle may introduce hydrocarbon contaminants into surface run-off waters. The active zone is thought to cause movement of heavy metals into the groundwater and surface waters, and a similar problem may exist for some of the oil and other organic components of OBM. However, no data are available to assess this option.

While land-spreading for water-based mud (WBM) wastes has been considered a practical method of disposal, there is concern that, during summer thaws, the base oil may migrate when OBM is involved, making this option unattractive to many. Use of solidifiers may mitigate against this problem, but again there are no data to assess the long-term potential for oil seepage.

Incineration, provided it is carried out in an environmentally acceptable manner, followed by landfill of the ashed material, appears to be a suitable method for onshore disposal of OBM. Further work may be necessary to determine the suitability of certain incinerators to deal with drill cuttings contaminated with OBM.

In addition to the review of disposal options for oil-contaminated cuttings, cuttings treatment systems, in conjunction with routine solids control equipment, were evaluated. The twenty-four systems were rated with respect to: (i) engineering and logistical considerations; (ii) environmental considerations; and, (iii) financial considerations, and presented in a series of matrices. The treatment systems were grouped into four general categories: spray wash, immersion wash, thermal, and stabilization.

A ratings scale (1-4) is presented for each engineering and logistic factor considered, which included: processing capacity; cleaning performance; size, weight and power requirements; process supplies required; safety concerns; manpower requirements; vessel support requirements; and, shorebase support requirements. The type of base oil used was not a factor in the ratings.

For the environmental considerations, a ratings scale was used to compare the relative environmental consequences of marine and onshore disposal of cuttings from each of the treatment system options. For marine discharges, three geographical/seasonal regions were assessed; shallow-waters areas (< 20 m) during ice cover; shallow-water areas during open water season; and the deeper water (> 20 m) regions of the Beaufort Sea and high Arctic islands. The relative impact of two different base oils - diesel and low-aromatic (< 1%) - were also assessed. Onshore disposal options compared the environmental consequences between poorly- and well-constructed, and maintained, burial locations.

Financial considerations included both the capital and operating costs of each treatment and disposal option. The type of base oil used did not significantly affect the overall operating costs and therefore was not a factor in the comparisons.

While the selection of a treatment and disposal option for oil-contaminated cuttings requires site specific information, the following points are important to remember:

- there are limited Arctic field data to assess the effects to the marine environment from the discharge of cuttings contaminated with oil;

- there is a similarity in the effects to the marine benthic environment from cuttings contaminated with both low-toxicity drilling muds and from diesel-based drillings muds;
- there has been very little experience in the use of cuttings treatment systems in the Arctic environments;
- offshore disposal of cuttings is most cost-effective for offshore drilling, providing that the degree of seabed disturbance is environmentally acceptable;
- the onshore disposal of cuttings is most cost-effective for onshore drilling operations and, providing certain criteria are met, can be environmentally acceptable, and,
- onshore disposal of cuttings from offshore drilling operations is the least cost-effective and will require detailed study of both engineering and logistical considerations related to transportation.

RÉSUMÉ ADMINISTRATIF

Dobrocky Seatech Ltd., avec l'aide de Technifluids et du Institute of Offshore Engineering de l'Université Heriot-Watt (R.-U.), a préparé un rapport passant en revue les différentes options utilisables dans l'Arctique canadien pour le traitement et l'élimination des déblais contaminés par des boues de forage à base d'huile (OBM).

L'équipement habituel de contrôle des solides ainsi que 24 systèmes de traitement additionnels ont été étudiés et les conséquences des méthodes d'élimination offshore et terrestre ainsi que de l'incinération ont été évaluées dans chaque cas. Le rapport est axé sur l'information permettant d'aider à la prise de décision par les exploitants et les organismes de réglementation. L'information de base sur le milieu physique, sur les effets écologiques des déblais contaminés par l'huile et sur la technologie du nettoyage des déblais est revue et sert à l'élaboration de matrices permettant aux exploitants d'évaluer les conséquences techniques,écologiques et financières du choix d'un système de traitement et d'une méthode d'élimination.

Le vent, les vagues, les courants et les glaces constituent les principaux facteurs influençant la dispersion des déblais produits sur un site offshore. L'action des vagues aura une influence importante en eaux peu profondes mais à

une profondeur de plus de 20 m, l'effet semble mineur. Les courants, surtout en eaux peu profondes et en période d'eaux libres, jouent un certain rôle dans la dispersion des déblais aux sédiments du fond. De hauts niveaux de sédiments en suspension, comme ceux que l'on retrouve à la plume du fleuve Mackenzie, peuvent aussi fournir un substrat propre pour la recolonisation de surfaces contaminées par les déblais. Les glaces influenceront surtout le transport et la logistique de soutien bien que l'affouillement puisse influencer la dispersion des déblais en eaux peu profondes.

Il existe peu de données sur les effets écologiques des déblais contaminés par des boues de forage à base d'huile sur le milieu marin de l'Arctique. La plupart des renseignement dont on dispose proviennent de données recueillies dans les champs de la mer du Nord. Les effets de ces déversements sur le fond marin ont été décrits en termes de « zones d'effets » qui comprennent l'enfouissement complet à proximité du site de déversement, la transformation en un enrichissement organique et un retour graduel aux conditions préalables à des distances plus éloignées du site de forage. La forme et l'étendue de ces zones varient et dépendent beaucoup des systèmes de courants et de la nature des déblais répandus.

La toxicité des huiles de base et des boues de forage a été mesurée sous les aspects toxicité aiguë et chronique. Bien que les composés aromatiques soient susceptibles de jouer un rôle important dans la toxicité de différentes huiles à l'égard des organismes marins, il est moins évident que les déblais contaminés par des boues à base d'huile peu toxiques (LTM) aient des conséquences biologiques générales moindres par rapport aux déblais contaminés par des boues à base d'huile à diesel. Toutefois, il apparaîtrait que, dans la mer du Nord, les communautés benthiques exposées aux déblais contenant de l'huile à diesel retrouvent leur diversité normale à une plus grande distance que celles exposées aux déblais d'huiles de base à faible toxicité. Il semble également exister une corrélation entre la diversité benthique et la concentration des sédiments de naphtalène. La recolonisation de déblais peut être favorisée par l'utilisation de boues à base d'huiles peu toxiques. De même, cette possibilité de l'induction par oxydase à fonction mixte (MFO) dans les organismes marins sera probablement diminuée par la substitution d'huiles de base à faible toxicité à l'huile à diesel. La météorisation de l'huile provenant des déblais semble lente, avec des taux de filtration de 1-2 g/m^3/d cités aux cours d'études en laboratoire dans des milieux à basse énergie. Les taux de dispersion de l'huile seraient supérieurs dans les régions du littoral de la mer de Beaufort. On a conclu que les effets généraux sur l'environnement des déblais à base d'huile dans la mer de Beaufort et le Haut-Arctique seraient environ les mêmes ou inférieurs à ceux qui ont été rapportés pour la mer du Nord.

Les méthodes d'élimination terrestre comprennent l'enfouissement (fosses), l'épandage et l'incinération. Cependant, l'éloignement de l'Arctique peut créer de graves problèmes de transport et de logistique lors du transport des déblais en vue de leur élimination et un navire spécial serait probablement nécessaire. Le forage côtier et le transport des déblais seront limités pendant les périodes de gel et la fonte du printemps.

Les conséquences de l'élimination terrestre comprennent l'infiltration de l'huile dans les milieux terrestres ou aquatiques avoisinants et les dommages physiques causés par l'équipement lors de la construction ou de l'entretien du site d'élimination. L'enfouissement des déblais huileux dans le pergélisol, sous la couche active, peut immobiliser les substances, surtout si la fosse est bien construite et comporte un revêtement intérieur imperméable. Cependant, si l'enfouissement se produit dans la couche active de surface, au-dessus du pergélisol, les cycles de gel et de dégel pourront entraîner une contamination des eaux de surface par les hydrocarbures. On pense que la zone active entraîne un déplacement des métaux lourds dans les nappes souterraines et les eaux de surface et il se peut qu'un problème semblable se pose pour certaines substances huileuses et organiques des boues de forage. Il n'existe cependant pas de données permettant d'évaluer cette option.

Bien que l'on ait estimé que l'épandage terrestre des boues à base aqueuse constitue une méthode d'élimination pratique, on craint que l'huile de base dans les boues de forage à base d'huile puisse se déplacer au cours des dégels de l'été, ce qui rend cette option peu acceptable pour plusieurs. L'utilisation de solidifiants peut atténuer ce problème mais ici encore, il n'existe pas de données permettant d'évaluer les possibilités à long terme d'infiltration de l'huile.

L'incinération, lorsqu'elle est effectuée d'une façon écologiquement acceptable et lorsqu'elle est suivie par l'enfouissement des cendres, semble constituer une méthode acceptable pour l'élimination terrestre des boues de forage à base d'huile. Des recherches plus poussées peuvent être nécessaires afin d'évaluer l'utilisation de certains incinérateurs dans le cas de déblais contaminés par des boues de forage à base d'huile.

En plus de passer en revue les options en vue de l'élimination des déblais contaminés, les systèmes de traitement de déblais utilisés avec l'équipement habituel de contrôle des solides ont été évalués. Vingt-quatre systèmes furent évalués sous les aspects suivants : (1) ingénierie et logistique, (2) écologie, (3) financier. Les valeurs sont présentées dans une série de matrices. Les systèmes de traitement ont été regroupés selon quatre catégories générales : nettoyage par arrosage, par immersion, thermique et selon un processus de stabilisation.

Une échelle (1-4) est présentée pour chacun des facteurs d'ingénierie et de logistique étudiés : la capacité de traitement, la qualité du nettoyage, la taille, le poids et l'énergie nécessaire, les fournitures nécessaires au traitement, la sécurité, les besoins de main-d'oeuvre, les besoins de navires de soutien et les besoins de matériel sur la rive. Le type d'huile de base utilisé n'a pas été considéré.

Quant aux considérations écologiques, une échelle a été utilisée pour comparer les effets écologiques relatifs de l'élimination des déblais en mer et sur terre pour chacun des systèmes de traitement. Pour les déversements en mer, trois régions géographiques/saisonnières ont été évaluées : régions d'eaux peu profondes ($<$20 m) au cours de la couverture de glace, régions d'eaux peu profondes au cours de la saison d'eaux libres et régions d'eaux plus profondes ($>$20 m) de la mer de Beaufort et des îles du Haut-Arctique. L'impact relatif de deux huiles de base différentes - huile à diesel et aromatique faible ($<$1 %) a également été évalué. Les options d'élimination terrestre ont comparé les effets écologiques entre les sites d'enfouissement pauvrement et bien construits et entretenus.

Les considérations financières ont tenu compte des coûts d'immobilisation et d'exploitation pour chacune des options de traitement et d'élimination. Le type d'huile de base utilisé n'a pas eu d'effets importants sur l'ensemble des coûts d'exploitation et par conséquent, on n'en a pas tenu compte lors des comparaisons.

Bien que le choix d'une méthode de traitement et d'élimination des déblais contaminés par des boues de forage à base d'huile nécessite des renseignements spécifiques quant au site, on doit aussi tenir compte des points suivants :

- les données sur l'Arctique permettant d'évaluer les effets du déversement des déblais contaminés par des boues à base d'huile sur le milieu marin sont limitées,

- il existe une similitude entre les effets sur le milieu marin benthique des déblais contaminés par des boues de forage à toxicité faible et ceux des boues de forage à base d'huile à diesel,

- on possède peu d'expérience dans l'utilisation de systèmes de traitement des déblais dans les régions de l'Arctique,

- l'élimination offshore des déblais présente de meilleurs coûts-avantages pour le forage offshore à la condition que les perturbations du fond marin soient acceptables du point de vue écologique,

- l'élimination terrestre des déblais de forage offshore présente les coûts-avantages les moins intéressants et nécessitera une étude détaillée de l'ingénierie et de la logistique en ce qui a trait au transport.

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1.0 INTRODUCTION

A number of significant oil and gas finds have recently been announced by operators in the Mackenzie Delta and high Arctic, and there is considerable interest in further delineating the extent of these structures. An expected increase in directional drilling, a need for faster drilling rates, and the lithology of the region have led operators to consider the advantages of using an oil-based drilling mud (OBM) rather than the water-based muds (WBM) currently in use.

A number of environmental concerns relate to the use of OBM. In early formulations, diesel was the primary base oil used in the preparation, but there were concerns about the high toxicity of the mud, primarily a function of the amount of aromatic compounds present. More recently the use of alternative base oils (with lower aromatics) have reduced the short-term toxicity, but the long-term fate and potential environmental effects of cuttings contaminated with OBM are still under review and study.

The Arctic marine environment is considered by many to be particularly sensitive to the effects of waste discharges and habitat disruption. To date, there has been only limited use of OBM in the Arctic and only one well has discharged cuttings to the marine environment, on an experimental basis. However, the expected increased interest and the uncertainty that exists with respect to effect on the environment of OBM, has emphasized the need to consider all the potential options available for the treatment and disposal of contaminated cuttings in the Canadian North.

In addressing this need, this study, funded by the Environmental Studies Revolving Fund (ESRF), assessed the different options available, considering a variety of base oil types and geographical locations. Based on a thorough search of the literature, plus the informed judgments of professionals experienced in the scientific, engineering, and operational aspects of northern drilling, this report is intended to be used as a first step in providing a decision guide for both operators and regulatory agencies.

2.0 PHYSICAL OPERATING ENVIRONMENT

2.1 GENERAL

To assess the different options available for the treatment and disposal of contaminated cuttings, it is important to recognize the operating constraints and physical processes which are a part of the Arctic environment.

Conditions that strongly influence the movement of cuttings in marine waters include wind and waves, currents, density stratification (thermoclines, pycnoclines), sedimentology, and ice. For onshore disposal, permafrost and hydrological features are important, whereas air circulation patterns may influence incineration options.

Factors that influence daily operations and, therefore, should be considered when discussing the use and efficiency of cuttings treatment systems, include ice, precipitation, visibility and daylight, temperature, geological features, and transportation and logistics.

This section is intended as an introduction to conditions that must be considered when deciding on treatment and disposal options.

2.2 FACTORS INFLUENCING DISPOSAL OPTIONS AND OPERATING CONDITIONS

2.2.1 Waves

Waves are generated only during the open-water season, which occurs from about mid-July to mid-October. Despite this short period, waves are the most significant modifying process of the Beaufort coastal zone. Open-water wave characteristics are as follows:

- **background waves** that are less than 1 m in height, account for less than 30% of the annual wave energy and occur 78% of the time;
- **intermediate storm waves** that are 1-2 m in height, account for nearly 50% of the annual wave energy and occur 20% of the time; and
- **severe storm waves** that are greater than 2 m in height, account for 20% of the annual wave energy and occur less than 2% of the time.

The directions of dominant wave approach for six locations in the Beaufort Sea (Figure 2.1) indicate that most of the storm-wave energy originate from the northwest (Harper et al. 1985).

Wave action is important in sediment transport, or the movement of drilling solids, especially for shallow, exposed drilling sites. Drilling solids may build up for extended periods at certain times of the year, but one major storm event can be sufficient to move the entire layer of solids that had formed. Harper and Penland (1982) concluded in a review of sediment dispersal in the Beaufort Sea that:

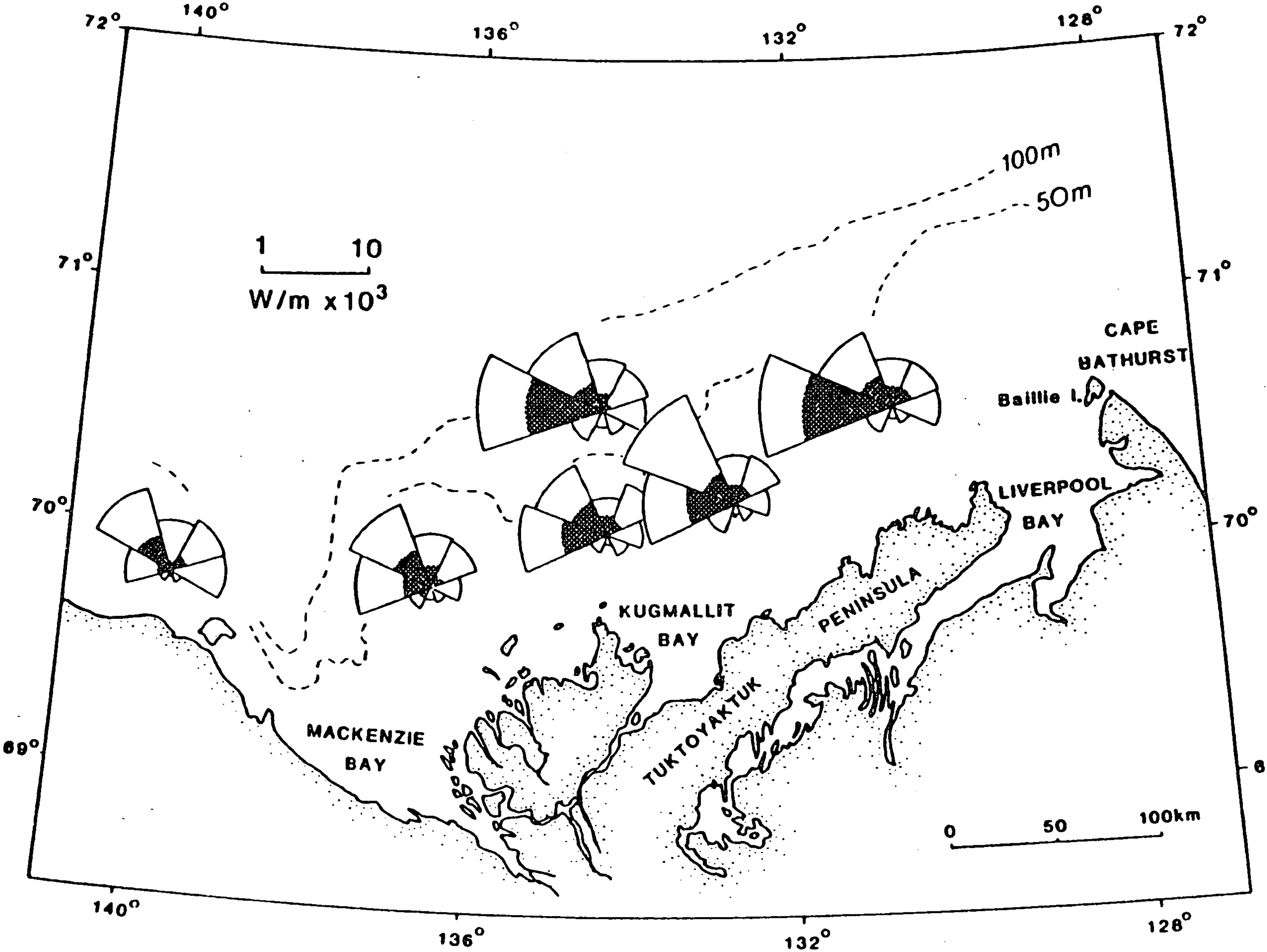

Figure 2.1 Wave power roses computed from wave climate summaries (Baird and Hall, 1980). The wave power components due to waves greater than 2 m in height are shown as the shaded portion of the wave rose (From Harper and Penland, 1982).

- the shelf landward of the 10-m contour is dominated by wave action with depths landward of 5-m depth disturbed nearly 50% of the time.

- the shelf between the 10-m and 20-m contours is occasionally disturbed by wave actions (1-10% of the time).

- the area of the shelf between 20-m and 35-m depths is occasionally disturbed by wave action (<1% of the time), but is, for the most part, dormant.

Based on this analysis, the 20-m contour was used in determining the effects of contaminated cuttings on the marine environment (see Section 6).

The extent to which the sediments are influenced by wave action is dependent on both the water depth and the height and period of waves. For example, based on 13 years of data, the mean Beaufort Sea summer wave has an amplitude of 0.75 m and a period of 5-7 s[1]. This wave will have a major influence on the bottom sediments in depths of a few metres, but will have no significant effect on sediments deeper than about 20 m. During storm events, however, the maximum water depth that will be affected by the waves will also increase.

2.2.2 Currents

Tidal currents are small in the Canadian Beaufort Sea (Fissel and Birch 1984) and currents in the shallow coastal areas of the Beaufort Sea are primarily driven by winds and by the discharge of the Mackenzie River. The general circulation patterns that occur under the two dominant wind directions are illustrated in Figure 2.2. Superimposed on these patterns are the flow of estuarine circulation established by the Mackenzie discharge.

Local current patterns vary, depending on coastal orientation and configuration. However, in shallow waters, currents are typically in the order of 50 cm/s and values of 100-150 cm/s have been recorded [2]. Bottom currents in deeper water (greater than 20 m) are much lower, typically less than 30 cm/s.

Currents will play a major role in the dispersal of cuttings and associated fines discharged in marine waters. The strength and direction of the currents present, the existence of a density layer (see Section 2.2.5), and season, will all be factors in assessing the effects on the environment.

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[1] G. Spedding, Esso Resources, Calgary, Alberta, personal communication, 1986.

[2] E. Birchard, Esso Resources, Calgary, Alberta, personal communication, 1986.

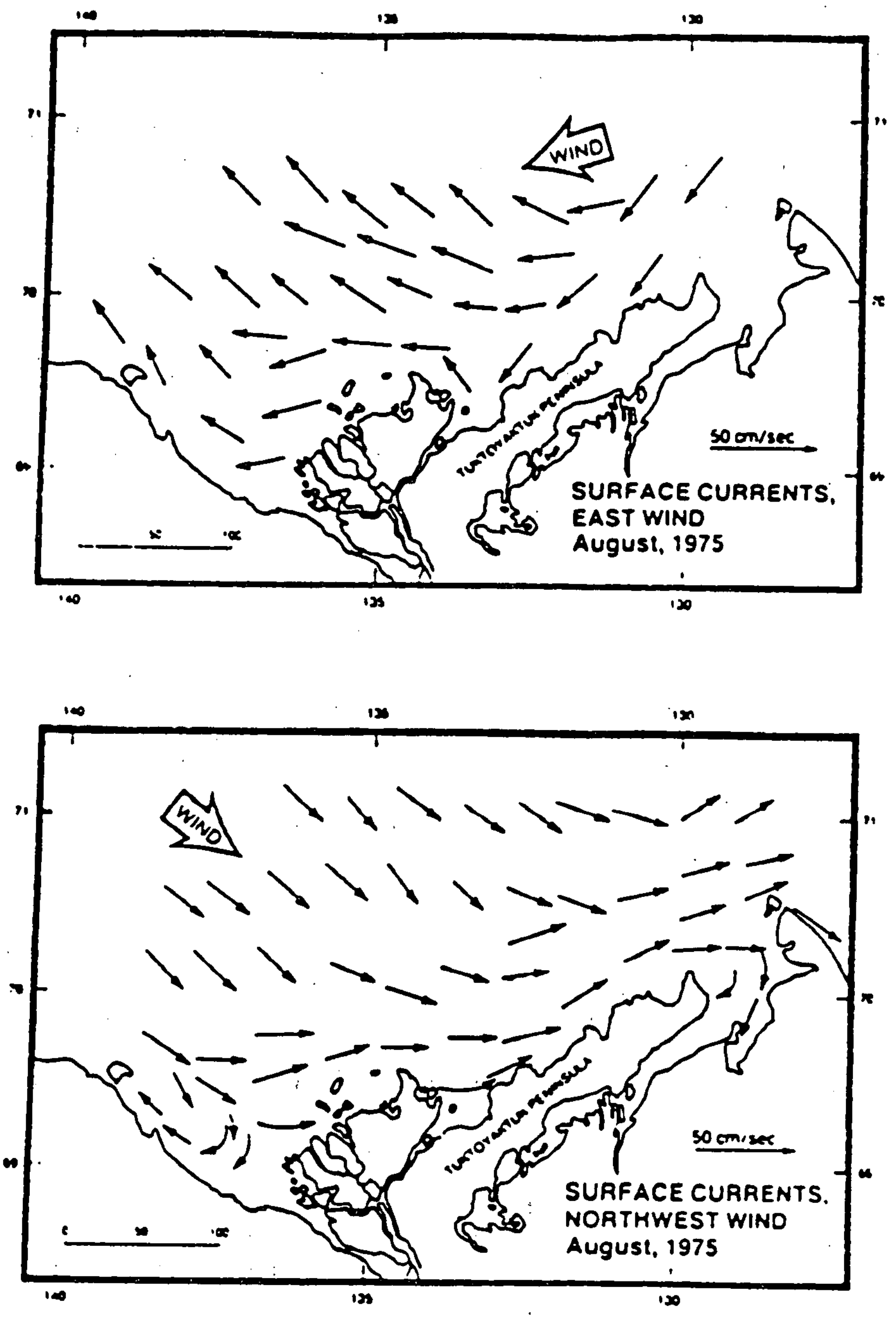

Figure 2.2 Wind-driven circulation patterns in the southern Beaufort Sea (from Milne and Herlinveaux, 1977).

Once the cuttings have settled, their redistribution and ultimate fate depends upon many environmental factors. The most important factor is the strength and duration of the bottom currents; tidal, wind-driven, and, in shallow waters, wave-induced. However, the degree and rate of deposition by natural sediments and ice cover must also be considered, especially for the southern Beaufort Sea.

In the Beaufort Sea, during times of ice cover, discharged cuttings or drilling muds will settle directly around the discharge point. During summer open-water conditions, storm and wave action will likely resuspend this material. The cuttings may be mixed in with, or buried by, material eroded from a sacrificial beach, or by sediment from the Mackenzie River or by both.

After freeze-up, with the low currents present during this period, little movement of cuttings can be expected although there may be some ice scour in shallow areas (e.g., the rubble field adjacent to drilling platforms). Considerable ice scouring can occur, however, during break-up, during summer ice-flow movement, and during freeze-up, particularly as the ice piles up around a drilling platform or island.

2.2.3 Sea Ice

Most of the Arctic Basin is covered with an ice pack, with an average thickness of 3 m. In the Beaufort Sea, the pack ice moves in a clock-wise gyre. Open water develops in the late summer in the southern Beaufort Sea and Mackenzie Delta but many of the straits and channels between the Arctic islands (e.g., the northwest passage) remain clogged with large, multi-year ice floes, and are, at best, navigable by non-icebreaking vessels for only a six-eight-week period in August and September (Anon 1982; Environment Canada 1983).

Sea ice occurs in various stages of development, from young ice (less than 30 cm thick) to first-year ice (30-200 cm) and multi-year ice (greater than 200 cm thick). Sea ice moves in response to currents and winds. Areas of open water are created when ice moves apart whereas large pressure ridges, up to 10 m high, may form when large ice masses converge.

Sea ice reforms annually in the Beaufort Sea and limits the open-water season to about three months (mid-July to mid-October). The presence of sea ice also effectively limits wave activity to these three open-water months. The presence of pack ice offshore further restricts wave action, even during the open-water months, so that the Beaufort Sea is a comparatively low-wave-energy environment.

In the Beaufort Sea, there are three principal ice zones: fast, transition, and polar pack. Fast ice is anchored to the shoreline or sea bottom by ridge keels and is more or less stationary. It grows out from the shore to about the 20-m bathymetric contour by mid-February. The ice is usually less than one year old and measures 1-2 m in thickness.

The polar pack in the Beaufort Sea is comprised principally of multi-year ice, which includes heavily-deformed ice such as rubble fields.

The pack ice rotates clock-wise around the Beaufort Sea at an average rate, at its edges, of three kilometres per day. In summer, during the open-water season, storms can cause an invasion by the polar pack ice, during which large floes (up to 8 km in diameter and 25 m thick) can move shoreward at speeds up to 2 knots.

The transition zone lies between the polar pack and the fast ice. The width varies from as little as 50 km to more than 320 km. This zone is generally made up of first-year ice and is dynamic in nature, often causing many pressure ridges and rubble fields to form.

Drilling has occurred in the fast ice in the Mackenzie Delta area, in the Beaufort Sea transition zone, and off ice platforms on the polar pack of the high Arctic. The main effect of ice will be on vessel support, but its presence will also influence some marine disposal options, such as the location of an outfall, as well the mixing of cuttings, once discharged.

2.2.4 Suspended Sediment

Concentrations of suspended sediment in the southern Beaufort Sea vary from less than 0.1 mg/L to more than 100 mg/L (Bornhold 1975; Harper and Penland 1982). High levels of suspended sediment are associated with the Mackenzie River plume, particularly inside the 10-m bathymetric contour.

The estimated, long-term (10,000 years), consolidated sedimentation rates in the Beaufort Sea off the Mackenzie Delta vary between 203 mm/yr in depths less than 10 m, to 1-3 mm/yr in 10-20 m of water, and 0.5-2 mm/yr in 20-40 m (Harper and Penland 1982).

Sedimentation of suspended solids will provide a "clean" cover over the cuttings and may enhance the biological recovery of the area. However, anoxic conditions may remain under this layer, limiting infaunal recolonization.

2.2.5 Hydrology

Northern Canada is covered by numerous lakes with an intricate network of surface drainage channels. The Mackenzie River, the largest in Canada, drains northward from Great Slave Lake and flows toward the Arctic Ocean where the Mackenzie Delta constitutes a region of channels and lakes.

The rivers and streams in northern Canada are dominated by snow effects. Hydrologically, the spring is a particularly active period. Snowmelt produces high run-off which, during break-up, is usually associated with the highest water stages. In the smaller streams between 25% and 75% of total run-off may take place within a two-week period. The annual high peak flows are usually produced by summer rains; on glacial-fed streams these flows result from a combination of glacial melt and rain. The prediction of the time of break-up and the magnitude of the annual flood is an important concern; for the Mackenzie River, break-up commences in May whereas freeze-up begins in early October (Environment Canada 1983).

The Mackenzie River is a major influence on the oceanography of the shallow Beaufort Sea. The low salinity and warmer temperature of the water creates a permanent pycnocline, or density gradient, over the delta waters during freshet and summer months. Generally, the pycnocline decreases in an offshore direction. Plume thickness, as defined by the pycnocline depth, can vary from 2 to 10 m.

The pycnocline influences the distribution of smaller-sized particles. Disposal of cuttings below the pycnocline would help to confine the dispersion of the discharged material. If the cuttings were discharged above the pycnocline, the likelihood of greater dispersion, because of the more active near-surface flow, would increase.

The hydrography of the smaller lakes and streams can affect the eventual water quality and distribution of contaminants from burial pits and sumps, especially during the spring melt. The environmental consequences are discussed in greater detail in Section 3.2.

2.2.6 Permafrost

The extended winter period in the Arctic, along with a relatively short period when temperatures are above freezing, results in the formation of perennially frozen ground, or permafrost, to depths of about 600 m. Above the permafrost is an active layer, 0.3 to 0.6 m thick, which thaws in summer and refreezes in winter (Environment Canada 1983).

Ice is an important component of permafrost in some areas (including the Mackenzie Delta) because it can lead to geotechnical problems related to the heaving of the ground or the melting of ice-rich permafrost. If the burial of OBM cuttings occurs in the surface active layer, freezing and thawing may introduce oil to surface run-off. However, if burial were below this active area, the cuttings material would likely remain frozen indefinitely.

The environmental implications of landfill or sumping options for waste disposal of cuttings are presented in Section 3.2.

2.2.7 Geological Characteristics

The zone of potential hydrocarbons in the Beaufort Sea is about 30-40 million years old. The lithologies encountered (Earl and Fedirko 1985; A. Hippman[3]) include:

- **delta front**: in shallow waters and on Mackenzie Delta; consists of unconsolidated sand, silt, and shale; pore pressures are normal;

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[3] J.A. Hippman, Dome Petroleum Ltd., Calgary, Alberta, personal communication, 1986.

- **prodelta**: occurs in deeper water, consists of unconsolidated shales; moderate-to-high over-pressures; and

- **basin**: occurs in deeper water; consists of shale, silt, and sand; moderate-to-high over-pressures.

One feature of Beaufort geology is the shale diaper, which is the result of rapid deposition of mud, clay, and silt with little amounts of sand. During compaction, no escape route exists, water is trapped, and the sediments can contain as high as 40% water. If disrupted, the diapir will push up sediments above it and potential petroleum traps can be formed.

When drilling through a shale diapir, the tendency is for the formation to fall, or spill, into the borehole which is a major cause of the hole-instability problems encountered in the Beaufort.

Beaufort Sea formations tend to disperse into the drilling fluids when using WBM. These formations are generally unconsolidated and unlithified, with a median particle size of solids coming up the well-bore ranging from 7 to 42 µm. The unconsolidated nature of these formations is one factor in recent considerations for using OBM.

In the high Arctic, the geology is more mature and competent than that in the Beaufort Sea and Mackenzie Delta, and cuttings tend to have a larger median size.[4]

2.2.8 Wind

Winds throughout the Arctic can reach speeds in excess of 40 km/hr, with gusts up to 90 km/hr (Anon. 1982). The effects of temperature are magnified by the "wind-chill" factor, which will affect operations as discussed in Section 2.2.10. In addition, "blizzard" conditions (e.g., snow or blowing snow, winds over 40 km/hr, and temperatures below -12°C) will greatly restrict outdoor activities and movements. Blown snow may occur as much as one quarter of the time during the winter (Environment Canada 1983).

Wind is the primary cause of pack-ice motion, and largely determines whether it is a good or bad year for ice. Ice, in turn, will affect both transportation logistics (see Section 2.2.12) and bottom scouring in shallow waters (see Section 2.2.3). In shallow waters, wind and waves (see Section 2.2.1) will dominate the movement of sea-bed sediment and the generation of ocean currents (see Section 2.2.2).

2.2.9 Temperature

Mean daily temperatures in the Northwest Territories are highest during July, averaging about 8°C near the Mackenzie Delta and about 4°C in the Arctic Islands. More important for operations, however, are the

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[4] B. Hans, Technifluids, Calgary, Alberta, personal communications, 1986.

temperatures during the winter months, which average about -27°C between November and March in the coastal regions of the Arctic and nearly -31°C in the Arctic Islands (Environment Canada 1983).

Low temperatures will hamper most outside activities. Workers and equipment must be protected and insulated as much as possible, thus putting physical constraints on some types of cuttings treatment options. Work in the open is slower and less efficient, which may affect more complex treatment systems. Low temperatures also increase the problems of maintaining and operating the equipment.

2.2.10 Precipitation

Total precipitation in the Arctic is low, with about 50 to 60% falling as snow. In the coastal areas of the Beaufort Sea (e.g., Sachs Harbour), the annual average precipitation is about 11 cm, whereas in the Arctic Islands (e.g., Alert), it averages about 15 cm (Environment Canada 1983).

The main influence on operations offshore will be on logistics support and will likely be of short duration. Excessive rainfall or meltwater could, however, be a factor in onshore burial options.

2.2.11 Visibility and Daylight

Reduced visibility may disrupt schedules of outside activities and logistics support. White-out caused by low cloud, diffused light, or blowing snow, can be particularly severe. Fog conditions most often occur during the summer, but ice fog can also sometimes occur during winter months. Daylight is reduced during the winter (November-January) to near 24-hour darkness and, as a result, illumination must be provided for all activities 24-hours per day.

2.2.12 Transportation and Logistics

The Arctic poses problems for exploration and production by its remote location. Operations from platforms offshore will be isolated by ice and distance from convenient sources of major resupply for as long as six to nine months at a time. Storage capacity is required for all materials, including drilling fluids, process supplies, and fuels, as well as staples for the crew.

Exploration to date in the Arctic has been carried out using various approaches. Wells have been drilled in the hard-freeze winter period from offshore man-made ice islands or from onshore locations; from gravel pads or pilings at onshore, summer locations; during open-water periods from drillships, or from bottom-founded structures (e.g., man-made gravel islands and mobile caissons). Some drilling year-round has been done from gravel pads, both onshore and nearshore.

Each of these approaches suffers constraints of cost and time. For example, an exploration well in the deeper waters using drillships, will usually require two drilling seasons to complete and test, and operations are susceptible to shut-down during summer ice invasions. In the high Arctic of the Canadian Archipelago, the open-water season is too short, and the water depths are too great (300-600 m) to use drillships, so drilling is done only in winter from man-made ice islands. Drilling from sandbag retained or sacrificial-beach islands, or from the several different types of mobile caissons, has extended the drilling season. Exploration is generally carried out during the winter period after construction of islands or supporting berms during the previous summer.

The season in which conventional shipping operations can take place is restricted to a short period, usually from July to October. To extend the season, prior to and after this period, supply vessels require ice-breaking support or need to be of ice-breaker class themselves. The costly offshore drilling vessels have been designed to minimize the need for resupply during periods of ice cover, so operations involving continual vessel movements would defeat the design purpose (see Section 6.3).

Cuttings treatment and disposal options involving shore-based facilities will likely require a dedicated vessel. Because space is at a premium on drilling vessels, little room would be available for storing wastes generated from the drilling operations. This would generally preclude shipping of waste containers at regular intervals from the rig, thereby requiring a vessel or barge on standby for waste storage.

Onshore drilling will be restricted by freeze-up and break-up. Generally, operations can begin by December 15, continuing to about mid-April, before the spring thaw and break-up. During the summer, operations on the tundra are more difficult because the instability of the wet terrain and the increased likelihood of its damage by vehicles.

3.0 ENVIRONMENTAL CONSIDERATIONS

3.1 OFFSHORE DISPOSAL

3.1.1 General Considerations

The fate of drilling fluids and cuttings discharged into the marine environment is determined by diverse physical processes (sea state, currents, and dissolution of soluble components), chemical processes (reaction, sorption onto particulates), and biological processes (incorporation into the food web). All these processes serve to disperse, change, or concentrate constituent materials (National Academy of Sciences 1983).

The discharged materials are distributed by the dispersive energy of the ocean at the disposal site which, in turn, is a function of wind, tide, waves, and mean currents. Dispersion will vary with site location and water depth because of the factors that influence the turbulence and, thus, mixing in the water column and in the bottom boundary layer. These factors include:

- wind-driven and tidal currents;
- ice cover and bottom-scouring by ice;
- the topography of large-scale bed forms;
- vertical density stratification (temperature and salinity);
- presence of suspended sediments;
- variable sea bed conditions (bioturbation, bed forms, and near-bed transport); and
- storm events.

In the case of cuttings discharges, the relatively large particles will settle rapidly near the well site. Soluble and particulate fluid additives adhering to the cuttings will, to some extent, be washed off as the larger particles settle. Ayers et al. (1980) found that over 90% of discharged water-based drilling fluid solids settled directly to the bottom, in a study carried out under calm sea conditions in the Gulf of Mexico. They found that the distance the cuttings travelled from the well site, and the settlement time, were primarily a function of current and water depth.

In waters deeper than 20 m, or in areas that are ice-covered for large portions of the year, the likelihood of cuttings being significantly dispersed by wave action decreases. In the deeper-water drilling areas of the high Arctic, for example, the bottom sediments will rarely, if ever, be influenced by wave action.

3.1.2 Environmental Implications of OBM Cuttings Discharged Offshore

A) North Sea Studies. The majority of the studies on environmental effects of discharged oil-based cuttings come from the North Sea. There is virtually no comparable information on Arctic areas, although some experimental studies are currently in progress.

The conclusions of a United Kingdom (U.K.) working group on the environmental effects of OBM cuttings are pertinent to this discussion (Davies et al. 1984). They found that despite both differences in inputs from different platforms and the variations in sea-bed area at different locations, the sea-bed chemical and biological effects associated with these discharges could be summarized in terms of four zones each affected differently (Table 3.1).

Zone I (Davies et al. 1984) is typified by an impoverished and highly-modified benthic community. Beneath, and in the immediate vicinity of the platform, biological effects result mainly from physical burial of the natural sediment which can lead to anaerobic conditions. A number of workers have noted that OBM cuttings are cohesive and undergo little resuspension (Blackman and Law 1981). In the laboratory, it was found that when diesel-based cuttings had an oil content of greater than 4-5% by weight, even those containing angular sand grains aggregated into large pellets which sank rapidly (100-700 m/hr). The authors concluded that very little absorbed oil was stripped from the solids during settlement but that, after deposition, oil continued to leach slowly to the surrounding water.

Oiled cuttings can compact to form a bottom pavement and as little as 1 cm of cuttings can seal off the natural sediments. Around the discharge point, the sea bed can consist of cuttings with no benthic macrofauna and sediment hydrocarbon concentrations usually exceeding 1,000 times background. In most cases studied, Zone I was confined within 250 m of the well site, although an outer limit of 500 m was used to include all fields.

In all North Sea fields studied, the major deleterious biological effects were confined within the 500-m zone and were associated primarily with (i) burial under the mound of cuttings of the sea bed (immediately adjacent, <100 m, to the platform) and (ii) the organic enrichment associated with the spread of oil from the cuttings. Sea-bed recovery in Zone I is likely to be a long process with layers of compacted cuttings persisting on the sea bed for several years in deep-water areas.

In the surrounding transition zone (Zone II), subtle biological effects can be detected as community conditions return to normal, generally within 200 to 1,000 m. The benthic community exhibits a classic successional response to point source organic pollution, with a peak of opportunist species occurring in the immediate vicinity of the platform. These species are very important because their abundance and high levels of productivity play an important role in the break-down of organic pollutants. In this regard, several correlations between chemical and biological conditions (such as sedimentary oil content and species abundance and the diversity and number of individuals) have been reported (Davies et al. 1984; IOE 1985a).

The shape and extent of Zone II is variable, and is largely determined by the currents and by the scope of the drilling operations. With greater currents and more extensive drilling this delineation may be extended to 2,000 m in the direction of residual current. From the little

Table 3.1

Zones of effect of discharge of oil-based mud and cuttings*

Zone	Maximum extent within range (m)	Biology	Chemistry
I	0-500 (usually <250)	Impoverished and highly modified benthic community (beneath and close to the platform the sea bed can consist of cuttings with no benthic fauna)	Hydrocarbon (HC) levels high; sediments largely anaerobic; HCs 1,000 plus x background
II	200-2,000	Transition zone in benthic diversity and community structure	Hydrocarbon levels above background; HCs 10-700 x background
III	800-4,000	No benthic effects detected	Hydrocarbon levels return to background; HCs 1-10 x background
IV	>4,000	No benthic effects	No elevation of hydrocarbons

* This study considered diesel and first generation (i.e., high aromatic) low-toxicity base oils only.
Source: after Davies et al. 1984.

information available, the surface sediments studied in this zone appeared to be aerobic, and biodegradation of hydrocarbons seemed to be taking place. A more rapid recovery of the transition zone was expected on cessation of drilling.

In Zone III (800-4,000 m) elevated hydrocarbon concentrations attributable to OBM were detected but no biological effects could be found.

Zone IV was the area beyond 4,000 m and no chemical or biological effects could be observed. Generally speaking, background levels were reached within 3,000 m, although this was extended for fields that produced very fine cuttings. In certain areas of the North Sea where offshore production platforms have recently been, or are about to be, installed it is no longer possible to find the "background" levels of sedimentary hydrocarbons that were observed 5 to 10 years ago. Extensive oil production activity in the East Shetland Basin, for example, appears to be producing elevated levels of sedimentary hydrocarbons to the south of this region.

The spread of cuttings has been found to be greatly influenced by particle size. Cuttings resulting from the use of an OBM are generally larger than when using a WBM and tend to fall, as agglomerations, more directly to the sea bed. The U.K. group also found that the extent of biological effects was greater from OBM cuttings than from WBM cuttings beyond the area of physical smothering (e.g., Zones II and III). These effects of oil-contaminated cuttings may result from organic enrichment of the sediment, or toxicity of certain fractions, such as aromatic hydrocarbons or both. It was estimated that sediment oil concentrations of 100 ppm diesel, or 2 ppm naphthalenes, would be expected to restrict many species of benthic organisms (Armstrong et al. 1979).

Davies et al. (1984) noted that there will be an overlap between the zone in both distance and pollutant levels and that the true picture will be a gradient of change away from the platform. The pattern of cuttings depositions reflects several factors including the prevailing current regime, depth of water, and height of the discharge point above the sea bed. The distances in Table 3.1 represent the maximum extent of the zones visualized at that time (1983), although this is currently under review.

The concept of "zones of effect" proved useful as a basis for summarizing the existing environmental effects as of 1982-83. With the large number of highly deviated wells being drilled from one platform in the northern North Sea, and the increasing use of OBM throughout most drilling programs, it may be that the "maximum extent of the highly-modified benthic community" (Davies et al. 1984) will not be contained within a 500-m zone. Similarly, whether the "benthos returns to normal" for the majority of the North Sea fields within 1,000 m remains to be conclusively proven, and the distance at which no benthic effects or evaluation of hydrocarbon levels is reached is still to be firmly established.

Long term recovery of an area following the cessation of discharge is likely to be affected by a number of factors (Davies et al. 1984) including:

- redistribution and spreading of cuttings:
- biodegradation or dissolution of the oil on the cuttings; and
- burial of the cuttings and recolonization of the surface sediment.

The U.K. joint-industry-government working group on OBM usage in the North Sea has been reconvened to discuss these topics in light of more recent field data.[5]

B. Scotian Shelf field results. A study, funded by ESRF, of the distribution of low-toxicity oil-based cuttings discharged at two well sites near Sable Island, Nova Scotia (Yunker and Drinnan 1987) supported the general conclusions of the U.K. group (Davies et al. 1984) for a deep-water (70-m) site but found that the U.K. summary overestimated the effects for a shallow-water site.

The two well sites studied were substantially different. One was located in about 16 m of water along the south side of the eastern bar of Sable Island, an area where bottom sediments were well-mixed by wave action. The other site was located about 19 km north of the middle of Sable Island, in about 70 m of water. At this site, the bottom sediments were influenced primarily by tidal currents during the study period.

At the shallow-water site, hydrocarbon concentrations were observed to drop off to a level 10 times above background at about 200 m from the well site. In comparison with the U.K. results (see Table 3.1), Zone II (the transitions zone) and Zone I (the impoverished zone) extended less than 200 m from the well-head. By extrapolation, the region of severe impact on the benthos would be within 200 m of the well site, although no grab samples were taken in that region. At this well, however, divers noted that the cuttings mound was only 20-25 m across. By inference, it is expected that the effects will be much less than those predicted by the U.K. group, because of the active sediment movement and redistribution. Similar processes may occur in parts of the southern Beaufort Sea, particularly in the shallow water areas during break-up, when ice scouring is predominant, and during storm events.

At the deeper-water site, hydrocarbon levels dropped to 10 times above background (the beginning of Zone III, no benthic effects, see Table 3.1) at distances ranging from 200 to 1,500+ m from the well-head. Hydrocarbon concentrations fell to two orders of magnitude above background (about Zone II, the transition zone) at distances ranging from 150-650 m from the well site. Concentrations three orders of magnitude above background (Zone I, the impoverished zone) were likely present at distances of about 100-400 m from the well.

Samples collected at the well-head at both sites, had aliphatic hydrocarbon concentrations that were five orders of magnitude above background. However, at the shallow site, the cuttings mound, which originally was deposited in a compact pile (24 m x 20 m, and 30 cm deep)

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[5] J. Davies, Department of Agriculture and Fisheries Marine Laboratory, Aberdeen, Scotland, personal communications, 1986.

under the drilling rig, was completely dispersed within a few months (diver observations). At the deeper well site, substantial amounts of oiled cuttings were found in the region of the well-head during post-drilling sampling even though the discharge of cuttings had stopped nearly a month earlier.

C) Weathering and biodegradation. Visual and laboratory observations (Blackman and Law 1981) indicate that most diesel-oil-based cuttings are cohesive and this aggregation of particles can be expected to require high water velocities for suspension. However, there is some evidence of a hydrocarbon weathering grading away from a platform. Saltzmann (1982) found a change in the ratio of the parent compound and substituted naphthalenes with increasing distance from the Beryl A platform in the North Sea, and increasing weathering of aliphatic hydrocarbons with distance from the platform was demonstrated along the northwest transect from the Thistle platform in 1982, both of which suggest a gradual movement of the cuttings away from the platform (Davies et al 1984). The drill cuttings study on the Scotian Shelf (Yunker and Drinnan 1987) has also indicated that weathering of the hydrocarbons in sediments (up to n-C12) occurred, particularly in areas of considerable sediment mixing.

From the relatively few quantitative field studies of biodegradation of hydrocarbons in sublittoral sediments (Saltzmann 1982; Jones et al. 1983) it appears that, in the water column and in the surface sediments of the aerobic Zones II and III, the small aliphatic and aromatic (naphthalenes) molecules will be biodegraded quite quickly. On the other hand, the large three-, four-, and five-ring aromatics may be biodegraded two or three orders of magnitude more slowly (Massie et al, 1985).

Details of a laboratory study of the oxygen demand of oiled drill cuttings layered over natural marine sediments have been reported by Hutcheson et al. (1984). The total sedimentary oxygen demands (over a 30-day period) of low-toxicity oil-based drill cuttings (Conoco ODC) layered over both fine and course marine sediments in 1-, 2.5-, 5-, and 15-mm layers were measured in conjunction with redox potential (Eh) profiles and levels of selected trace metals in both pore waters and in sediments. Based on a series of measurements of oxygen demand over the 30-day study period Hutcheson et al. (1984) were able to derive multiple-regression equations to predict the oxygen demands of cuttings on both coarse and fine sediments, with time (days) and cuttings thickness (mm) as independent variables.

Redox potentials ranged from 310-601 mV. No negative potentials were recorded and no vertical Eh gradients were observed through cuttings into coarser sediments. The study also indicated that mobilization of mercury (Hg), lead (Pb), cadmium (Cd), and zinc (Zn) should not occur under conditions similar to those in the experimental program. Mobilization of copper (Cu), however, did appear to occur. With larger decreases in Eh it was noted that other changes in pore-water chemistry could have occurred.

In Zone I (in areas of low wave action), anaerobic conditions will prevail just below the surface of the cuttings pile and little or no biodegradation is likely below the surface bacterial layer. Under these circumstances capping of the cuttings by local sediment resuspension and deposition, and subsequent recolonization of the area in the aerobic deposit, seems the most likely mechanism of recovery (Davies et al. 1984).

It has been observed that direct leaching of oil from cuttings into sea water appears to be slow (Engelhardt et al. 1983, p.36) with initial rates of 0.1% of total oil per day and total losses in the order of 1-4% of total oil over a "substantial period of time." Poley and Wilkinson (1983) have suggested that, from laboratory studies, leaching rates of "oil from cuttings" (neither described) would be approximately 2 g/m^3/day. In spite of this apparent lack of availability, accumulation of non-polar hydrocarbons from low toxicity oiled cuttings has been observed to occur in parallel with lethal response in the few marine invertebrates tested (Hutcheson et al. 1984). The possible implications of this uptake on potential fish tainting have not been fully investigated, although recent reports from the Dutch sector of the North Sea give some indications of petroleum tainting of flatfish caught in the regions adjacent to oil production areas.

D. Toxicity studies. Most of the studies available to the U.K. group (Davies et al. 1984) were done on drilling operations that used either diesel oil, or the first-generation, low-toxicity oils, to make up the OBM. The much higher concentration of aromatics in these oils, relative to the oils usually used in Canada, is given by most workers as the reason the former have a much higher acute toxicity. Although the concentrations, types, and toxicities of aromatic compounds in either diesel oil-based, or low-toxicity, oil-based muds are important to know, the U.K. authorities do not propose to regulate low-toxicity, oil-based muds on the basis of aromatic content (Engelhart et al. 1983).

Analysis of a range of the low-toxicity base oil themselves (Blackman et al. 1983) showed some correlation between total naphthalene concentrations and high toxicity, although there were some exceptions. A working group of the joint API-European standardization task group on properties of drilling fluids was established in 1985 to investigate methods for the determination of the aromatic content of low-toxicity base oils, among other properties. At present there is no standardized method for the determination of the aromatic content of base oils used in drilling fluids and, thus, it is difficult to relate the toxicity of base oils to their "aromatic content." Furthermore, the wide range in toxicity of "low-toxicity" base oils compared to the uniformly low toxicity of drilling muds formulated using them (Blackman et al. 1983) raises the question of the suitability of short-term, acute-toxicity testing for assessing the effects on the environment of discharging these materials.

In Canada, Hutcheson et al. (1984) have assessed both acute (96-hour), and chronic (32-day), lethal toxicities of oiled drilled cuttings (low-toxicity base oil) to a variety of marine benthic species. They concluded that toxic aromatic compounds seemed to play no role in the toxicity response. Recently, interest in toxicity testing of oil cuttings has increased in the USA and additional information may be available in the future.[6]

Discussion at the Trondheim conference on oil-based drilling fluids (February, 1986) referred to the potential toxicities of various additives to OBM. The implications that such additives have on long-term effects in the Arctic may need to be investigated.

The benthic fauna beneath, and immediately adjacent to, the drilling platform will be completely buried by discharges of both diesel and low-toxicity oil-based mud cuttings, but there is little evidence that the latter will have less overall effect on the sea bed. The hydrocarbon load of low-toxicity, oil-based mud cuttings results in significant organic enrichment of the sea bed (Addy et al. 1984). Within the organically enriched area, hydrocarbon analyses point to active biodegradation, particularly of the n-alkane fraction. This degradation is accompanied by severe oxygen depletion in sediments within 250 m of the platform. However, although high hydrocarbon concentrations are clearly correlated to biological effects, this correlation does not necessarily imply a toxic effect because the faunal response is consistent with organic enrichment and not with direct toxicity.

Blackman et al. (1983) presented the results of the toxicity testing of both low-toxicity, and diesel, oil-based muds on brown shrimp. They reported that most low-toxicity base oils were at least an order of magnitude less toxic than the diesel equivalent. They also concluded that base oil toxicity cannot always be predicted on the basis of the aromatic content. In a subsequent study, the same group examined the effects of oil-based drilling muds in sediments on the settlement and development of biota (Blackman et al. 1985). An initial oil concentration of 1,000 times the background total hydrocarbon content was used in all cases. Over the 200 days of the experiment, there was a marked difference between the biota developing in tanks containing oil-based drilling muds and in the control tank, which received drilling mud solids only, without any oil. There was a difference in effect between two drilling muds based on alternative oils of moderate and low-aromatic hydrocarbon content, but a greater difference existed between these two muds and a diesel-based mud. When the total surficial sediment oil concentrations decreased, biota were observed to develop even in the diesel mud tank, even though the oil concentrations in the subsurface sediments remained high.

Blackman et al. (1985) concluded that although it is difficult to extrapolate from experimental tanks to deep-water, offshore oil fields, it is expected that surface recolonization will occur, even on sediments heavily oiled to a depth of several centimetres, once the surficial deposits are sufficiently clean. They also concluded that recolonization will be promoted by the adoption of low-toxicity, alternative-base oils in preference to diesel, but that the recolonizing communities are likely to be different from those in an unaffected area.

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[6] J. O'Reilly, Exxon, Houston, Texas, personal communication, 1986.

In another laboratory study, small quantities (<2-mm depth) of diesel oil-based cuttings (7-20% oil, w/w) produced some changes in a behavioural response pattern of the Norwegian lobster, Nephrops norvegicus, (e.g., the beat of the expedite on the third maxilliped), although flicking rates of the antennule and the time taken to identify and capture food were unaffected (Richardson 1984).

A recent report (IOE 1985b) has indicated that a bacterial isolate from oil-based cuttings was twice as efficient at using diesel than it was at using a low-toxicity base oil. This result probably reflects the diversity of potential carbon sources provided by the more complex diesel and may reflect co-oxidation mechanisms (e.g., oxidation only in the presence of other hydrocarbon or carbohydrate substrates). This may, in turn, lead to slower weathering rates of low-toxicity oil from cuttings and an increase in the potential for tainting of ground fish.

In Canada, a number of studies have been performed concerning the effects of oil-based mud cuttings on fish. Addison et al. (1984) observed no toxic effects of low-toxicity oil-based cuttings on winter flounder over a 24-day test period. Sub-lethal assays of these flounder, based on mixed-function oxidase (MFO) measurements, showed no induction either of MFO enzymes or of the cytochromes associated with them. Even in the "worst-case" scenario of prolonged static exposures, no untoward lethal or sub-lethal effects were noted on the winter flounder, a species which shows MFO induction in the presence of other hydrocarbons. There was little or no indication, even on injection of base oils, of MFO induction in several species of fish; MFO induction appears greatest with exposure to aromatic compounds but is no easily induced by alkanes.[7]

Also on the basis of mixed-function oxidase studies in fish, Payne et al. (in press) concluded that any potential for MFO induction by hydrocarbon-contaminated cuttings would likely be reduced by substitution of low-aromatic base oils for diesel. They also comment that different classes of aromatic compounds appear to affect the fish differently, pointing out the difficulty of trying to deduce any sub-lethal effects, such as induction of MFO enzymes, on the basis of total aromatic content.

3.1.3 Effects of Offshore Discharges in the Arctic

At present no information is available on the effects of OBM contaminated cuttings discharged to an Arctic marine environment, although a current ESRF study at two offshore well sites in the Beaufort Sea is addressing, in part, this topic. Other work in progress includes a leaching study of OBM cuttings under simulated, nearshore, Beaufort Sea conditions sponsored by the Department of Indian Affairs and Northern Development (IAND).

In many respects, the behaviour of the oiled cuttings in the shallow Beaufort Sea is expected to parallel both situations found at Sable Island

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[7] J. Osborne, Fisheries and Oceans, St. John's, Newfoundland, personal communication, 1986.

(Section 3.1.2b). Cuttings discharged during the open-water season will likely be well-mixed by summer storms (dispersed or buried similar to the shallow Nova Scotian site) and the cuttings pile will likely be scoured by ice flows during periods of summer ice movement and during freeze-up. Cuttings discharged through the ice after freeze-up can be expected to settle directly around the discharge point (similar to the deep-water, Nova Scotian site) because of the low currents usually prevalent during this time. As the ice cover breaks up, however, considerable scouring of the cuttings pile is likely.

3.2 ONSHORE DISPOSAL

Disposal of drill cuttings onshore is one alternative to offshore dumping. The implications arising from onshore disposal options, primarily the location of landfill sumps, are discussed in conjunction with alternatives, including land-spreading, dilution and dispersal in fresh water, and incineration.

Water-based mud wastes, from onshore exploratory wells in the Arctic regions, have been effectively handled by the use of sumps and subsequent burial (Beak 1974; Dames and Moore 1974; Canadian Petroleum Association 1977). Sump disposal involves the construction of a pit area, disposal of waste material and subsequent filling in of the sump with the original overburden material. This overburden in turn is often capped with gravel. Studies made during the past decade of abandoned Arctic wells show that when the proper construction and restoration criteria are met, drilling wastes can be effectively contained by sumps (French 1978a, b; French 1980; Smith and James 1979, 1985). In general, the area affected by sump construction and back-fill is in the order of 200-300 m^2.

Surveys of sumps made throughout the Arctic (in 1976-77) indicated that both the location of the sump (geographically and locally) and the timing of construction and restoration (seasonally) are the primary concerns with respect to construction of a sump. A major consideration with oil-based cuttings is that they may not freeze as completely as water-based muds, resulting in the potential for leaching from the sump. To date, there is insufficient information to determine the degree to which this leaching may occur.

3.2.1 Geographical Location

Substantial geophysical and climatic differences exist between high-Arctic and low-Arctic regions. High-Arctic tundra is characterized by both well-vegetated lowlands or oases (e.g., Banks and Southwest Cameron Islands) and barren polar deserts (e.g., Prince Patrick and Ellef Ringnes Islands). Low-Arctic tundra is deltaic, and is typified by the Mackenzie Delta. Differences between the two tundra (French 1978a) include:

- duration and magnitude of summer melt
- vegetation cover
- ground ice
- underlying bedrock
- accessibility to aggregate material.

A) High Arctic. Within the high Arctic, both polar deserts and well-vegetated areas exist. The well-vegetated lowlands are typically a surficial layer of beach materials covered by a thick organic mat, composed primarily of moss. Such areas are probably best suited for waste disposal by sumps (Smith and James 1979). Problems that may arise from construction and restoration of sump locations are outlined in Table 3.2.

Sumps should be of sufficient size initially to prevent overflow and to minimize terrain disturbance if additional sumps are needed. These regions frequently are associated with rivers and high drainage and sump location and construction must be sufficient to prevent undermining or erosion. Sumps also should be located away from any shoreline to prevent sea-water thawing and long-term erosion. If these precautions are taken, few, if any, problems are likely to occur.

More common are difficulties associated with the restoration stage, but these can also be mitigated provided that proper procedures are followed. The major problems are: (i) sump subsidence and collapse, which results either from the incorporation of snow and ice with the infill, from underground erosion, or from both; and, (ii) mixing of wastes and infill material (volcano effect) arising from the weight of the overburden collapsing the surface of the sump. The latter occurs when the sump is infilled before the wastes are completely frozen. Sump subsidence can be prevented by careful restoration practices, including the elimination of snow or ice from the infill material, construction of upslope drainage lines, and doming of the sump with gravel caps. The volcano effect can be prevented by late-winter restoration and by covering the sump with gravel aggregate.

Damage to vegetation can result from burial, crushing (or ripping), and direct toxicity from any surface oil leaking from the sump. Burial often occurs when the sump is too full and overflows at the edges, or by dumping the infill material on vegetation during sump construction. It can be avoided by correct sump size or storing infill material away from vegetation zones. Burial will also result in localized death of vegetation (lack of light and oxygen), although recolonization can occur by plants with aerial stems (Heginbottom 1973; Babb and Bliss 1974; Bohn 1974; Smith and James 1985).

Crushing and ripping of vegetation is generally caused by vehicular traffic and can be corrected by restricting traffic movement to the winter period. Contamination of vegetation may result from improper construction (see Table 3.2) or from spills during filling. The toxicity of cuttings from OBM systems on terrestrial vegetation is not known.

Polar deserts of the high Arctic are typically barren, arid regions that lack vegetation, wildlife, and ground ice. Many of the problems that might occur in wetter, more-vegetated areas would be avoided in this

Table 3.2

Summary of onshore disposal concerns for WBM

Problem	Cause	Solution
Non-containment	Sumps too small initially.	Additional sump; truck wastes elsewhere; modify existing sump
Terrain disturbance	Initial or additional construction in summer; trucking fluids.	Gravel dome; cease construction until winter
Volcano effect	Infilling when freezing incomplete	Domed gravel caps; winter infilling
Subsidence/collapse	Incorpation of snow/ice during infilling; water seepage	Pre-inspection in summer; careful infilling (no snow); drainage lines upslope
Lack of in fill	Meltout resulting in a heat sink over sump	Domed gravel caps
Fluid leakage	Ice lenses in walls during meltout; sump too full	Proper sump size
Vegetation kills	Contamination from: a)erosion b)spring runoff c)spills d)overflow (too full, volcano) Toxicity to plants unknown	a)Planting of native grasses b)Winter construction c)Careful handling d)Proper sump size
Burial	Overflow; location of infill material during storage	Proper sump size; locate away from vegetation zone
Crushing, ripping of plants	Vehicular movements during backfilling or transport	Winter movement only

Reference: French (1978a,b; 1980); Smith and James, (1979; 1985) region. On the other hand, sump construction and restoration costs would be higher because of the greater difficulty in blasting continuous permafrost and in back-filling frozen infill material. French (1978a), stated that land-spreading, or at least non-containment, of wastes may be a preferable alternative in these circumstances.

B) Low Arctic. Low Arctic tundra is best exemplified by the Mackenzie Delta: an ice-rich terrain covered by shrub vegetation (north of tree-line) and innumerable lakes and drainage channels. The climate is affected by its proximity to the Beaufort Sea, and above-freezing temperatures are reached in summer.

Use of sumps for containment of drilling wastes has been recommended for the low Arctic (Smith and James 1985). Similar guidelines apply for construction and restoration as discussed for the high Arctic. Problems associated with non-containment of wastes and terrain disturbances would be mitigated in a manner similar to the vegetated areas of the high Arctic (see Table 3.3).

Additional problems could arise from the thawing of the upper layer of the tundra, which would result in a melt-out of ice crystals in the permafrost. This melting could cause subsidence or collapse of the sump, leakage of waste material, enlargement of the sump, and the formation of standing water bodies. Standing water acts as a heat sink, thawing the overburden layer of the sump and allowing the infill and waste material to mix (volcano effect). Some of these problems could be overcome by using gravel aggregate to dome the sump after restoration, although use of natural disposal sites (e.g., borrow pits or enclosed lakes without sensitive biota) may be an alternative (French 1980; French and Smith 1980).

Burial of oiled cuttings in the permafrost, below the active zone, may immobilize the material, particularly if the sump is properly constructed, and includes a lining of impermeable material. However, no data are available to assess this option. The active zone is thought to cause movement of heavy metals into the ground and surface waters, and a similar problem may exist for some of the oil and other organic components of OBM, although this may also be a result of excess filling of the sump above the permafrost.[8] A properly maintained sump is likely to minimize this problem.

The low-Arctic, delta region is the most sensitive area for waste disposal because of its greater biological importance, greater human habitation, and annual thaw and flooding.

Environmental effects, other than on vegetation, from onshore disposal of WBM cuttings to date are not well documented. Table 3.3 outlines some the possible environmental concerns, particularly in relation to birds and mammals, which could result form improper sump construction,

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[8] D. Milburn, Environmental Studies Revolving Fund, Ottawa, Ontario, personal communication, 1986.

Table 3.3

Possible effects on terrestrial and estuarine biota from onshore disposal of OBM drill cuttings

Species	Effect	Mitigation	Comments
Birds			
Eiders, oldsquaws	Loss of insulation ability ingestion of oil, mortality due to leakage from sump to watercourses; will mistake oiled surfaces for open water	Allow wastes to freeze completely before restoring; careful handling of wastes	Large number of both species migrate through Mackenzie delta and Beaufort Sea. Summer most important period
Diving ducks scoters	Loss of insulation; ingestion; mortality due to direct contact with oil on open water, in particular, bays, lagoons and coastline; loss of prey species (contamination of mudflats)	As above	Large number of ducks summer in e.g., Mackenzie delta and along Beaufort Sea coast; species undergo annual moult, making them more vulnerable due to flightlessness
Shorebirds	Loss of habitat (marshes); loss of insulation due to contamination of marshes	As above; prevent oil from reaching marshy areas	
Peregrine falcon	Loss of prey species; possible contamination while hunting	As above	Endangered species: Mackenzie River Valley is one of two nesting sites for *anatum* race in NWT; feeds on waterfowl, shorebirds and small passerines
Snow geese	Loss of staging and breeding areas due to oil contamination; oiling of birds with loss of insulation and mortality	As above; protect staging & breeding areas	Mackenzie Delta and Yukon coastal plain are staging areas for geese during August-October; breed in High Arctic (e.g., Banks Island) during summer months
Kittiwakes	Mortality through oil contamination of open areas or resting sites due to loss of young, ingestion or loss of insulation	As above.	2-3% of Canadian population breed on Brown Island Batty Bay in high Arctic

Table 3.3 (continued)

Species	Effect	Mitigation	Comments
Mammals			
Caribou	Interruption of migration paths; loss of food sources due to loss of vegetation	Disallow dumping during April, August, September in migrating areas; protection of vegetation	Three migration paths in Mackenzie delta, Yukon, Alaska region
Wolves, Grizzly bears	Loss of prey species	As above	
Fish			
	Contamination of habitat and loss of prey species due to contamination of fresh water	Disallow dumping during summer months; proper instruction and operation of burial pit	Enter estuaries in spring (after melt-water); return to fresh-water in late summer to spawn or to over-winter
Cultural			
	Loss of domestic and commercial income or recreation due to oil contamination of foxes and other fur bearers or anadromous fish	Avoidance of high use areas; proper disposal management.	

or from restoration, or from accidental spills. The most likely effect associated with whole OBM disposal would result from the coating of feathers or fur.

3.2.2 Local Considerations

The local placement of a sump is particularly important in the low Arctic where the permafrost experiences spring thaw and annual flooding, during which the potential for ecological damage is greatest. Poor location may lead to erosion and to subsequent subsidence or collapse of the sump, with the potential for leakage of wastes and for contamination. Erosion by spring melt-out and alluvial streams can be prevented by a pre-inspection of the site during summer, whereas erosion by downslope drainage can be prevented by locating the sump in a shallow depression or, if that is not possible, by constructing drainage lines upslope.

3.2.3 Seasonal Concerns

To reduce the potential for problems, sumps should be constructed, filled and restored during the same winter, to minimize any thawing of the permafrost and to ensure the in-situ freezing of waste material. Terrain disturbances by vehicles are also minimized during the winter. In some areas (e.g., low Arctic and Mackenzie Delta) summer movement by heavy equipment is impossible.

Problems arising from subsidence, volcano effects, leakage resulting from degradation of sump walls, and excessive terrain damage were reported from surveys that investigated the effects of drilling operations during a summer, or over a two-winter, season (French 1978a; Smith and James 1985). Restricting equipment movement to winter, capping the sump with a gravel dome, locating the sump in a continuous permafrost location (polar deserts), or constructing and restoring sumps over a single winter season, would alleviate these concerns.

3.2.4 Alternatives to Sumps

While land-spreading for WBM wastes has been considered a practical method of disposal, there is concern that during summer thaws, the base oil may migrate when OBM is involved, making this option unattractive to many.

Discharge of oil-based cuttings to a freshwater environment has not been studied to date although reports on other drilling wastes have been prepared (Beak 1974; Hrudey et al. 1976). The use of small lakes as borrow pits may prove suitable providing there is sufficient protection to prevent groundwater contamination.

In areas where fish are resident, especially commercial and subsistence species, considerable environmental concern may exist. In rapidly flowing rivers with high sediment loadings, movement and burial of the cuttings is likely to occur but there is no information to predict how quickly this will occur or what effect it might have.

3.3 INCINERATION

One options for treatment and disposal of cuttings transported from shore or generated form onshore operations is to incinerate the material.

Few tests on the incineration of cuttings alone have been carried out. Milburn (1984) reported on the results of open-pit burning of whole mud wastes, and concluded that rotary kiln incineration (or similar equipment) would be required for complete disposal, especially for cuttings. However, the equipment is large, complicated and expensive and cuttings from several sources would have to be processed (e.g., a central treatment facility) to reduce costs.

National guidelines exist for air emissions from packaged incinerations, which should be considered when dealing with the incinerations of cuttings from oil-based muds. Emission limits area given for particulates, HCl and SO_2, but, as yet, not for unburnt hydrocarbons or heavy metals.

Provided that the incineration is carried out in a safe manner, and proper precautions are taken with regard to down-wind settlements or biological resources, it is anticipated that the effects of such operations would be negligible.

The ash from incineration operations would be landfilled, as described in Section 3.2. Because of the small volumes and the low oil content of the material, no problems are expected form this disposal option.

Dome/Canmar performed a series of incineration tests in 1985 on whole oil-based mud, formulated using both diesel and a low -toxicity base oil. Four separate incinerators were tested: a TOPS (Technical Offshore Petroleum Services) burner; a Saacke (rotary cup) burner; a reciprocating kiln; and an air portable incinerator. The rates of throughput of mud ranged from 400 bbl/day (TOPS), through 350 bbl day (Saacke), to 40 bbl/day (reciprocating kiln and air portable incinerator). The reciprocating kiln was also used to burn oil mud cuttings. Although this proved to be labour-intensive, it did produce a very clean waste product.

4.0 DEVELOPMENT OF CUTTINGS TREATMENT

4.1 USE OF OIL-BASED MUDS

With the increase in interest in offshore drilling in the USA, U.K. and, more recently, in Canada, it was found that WBM were not always suitable for the downhole drilling conditions encountered in some locations. Sensitive geological formations, such as shales, that slough when contacted with WBM, over-pressured clays, and water-soluble formations, such as salt and potash, were often encountered. These all made borehole stabilization difficult. Deviated drilling also became commonplace, with its associated torque and drag problems. To alleviate these difficulties, OBM was considered by many operators as essential for drilling highly deviated sections with often high differential pressures.

Oil is the native fluid of productive formations, and, therefore, should not adversely affect clays or soluble solids, such as salts, which may occur in a producing interval. For this reason, crude oil was used in the past to drill into a producing zone, to maximize the return from the reservoir. Many other advantages and beneficial effects of using oil as the drilling fluid medium were noticed, and OBM became more widely used. A number of advantages are associated with the use of OBM, including:

- to drill reactive clays and shales without exposing them to water, thus minimizing hole-related problems;
- to drill deep, hot holes where the lubricity and stability of WBM is insufficient;
- to drill or core productive intervals with a fluid approaching native state;
- to drill salt and evaporite zones that would wash out if WBM was used;
- to drill directional wells where rotary torque and hole drag from friction are high;
- to drill formations containing carbon dioxide or hydrogen sulphide;
- to act as a perforating and completion fluid;
- to act as a spotting fluid to free differentially stuck pipe;
- to serve as a packer or work-over fluid;
- to reduce corrosion;

- to provide resistance to contamination of the mud by formations; and,

- to reduce the treatment required to maintain desired mud properties.

The main advantages in using OBM in the Arctic relate to reduced formation damage and improved (shorter) drilling time, due, in part, to its lubricating capabilities. In addition, the use of OBM would facilitate delineation and production drilling.

Oil-based muds are also used to reduce hydration and sloughing of the borehole wall. Their use is particularly important in the Beaufort Sea/Mackenzie Delta areas where the generally unconsolidated nature of the formations has resulted in problems in the past. The reduced formation damage, especially in the zone of invasion, will improve the production characteristics of an oil- or gas-bearing zone.

The average time on site in the Beaufort is 91 days, of which 21 days are spent drilling.[9] Reducing the downtime due to borehole problems and improving the rate of drilling could mean a 10 to 20% saving of drilling time, or from $250,000 to $10 million per well.[10] In some areas, such as the offshore wells where drillships are used, it may be possible to complete a well within a single season compared with the two seasons it generally takes.

4.2 ROUTINE SOLIDS CONTROL

When a drill bit bores into a formation, rock cuttings are produced. Drilling fluid is pumped down the inside of the drill pipe and, on reaching the bit, the fluid jets the cuttings away from the bit and carries them up the annulus (the space between the drill pipe and borehole) to the mudline then on up to the platform. Because the mud should travel around a 'closed loop' if the drilled cuttings are not removed they will build up in the drilling fluid to the detriment of the whole drilling process. Thus, a solids-control system is installed with the prime purpose of separating drilled solids from the drilling mud and mud solids.

The general particle sizes which individual items of solids-control equipment will remove from liquids are given in Table 4.1. These figures will be affected by screen mesh number, cuttings particle size, density, and shape, as well as by liquid density and viscosity.

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[9] R. Engelhardt, Canada Oil and Gas Lands Administration, Ottawa, Ontario, personal communication, 1986.

[10] C. Johancsik, Esso Resources, Calgary, Alberta, personal communication, 1986. A. Hippman, Dome Petroleum, Calgary, Alberta, personal communication, 1986.

Table 4.1

On-structure equipment used for solids control

Solids control equipment	Particle size range (µm)	A.P.I. particle classification	Common name
Shale shakers	>2,000	Coarse	Cuttings
	2,000 - 200	Intermediate	Cuttings
100 mesh	>140	Medium	Sand
150 mesh	>104	Medium	Sand
200 mesh	> 74	Fine	Silt
325 mesh	> 44	Fine	Silt
Desanders	250 - 74	Medium	Sand
Mud cleaners	74 - 44	Fine	Silt
Desilters	74 - 44	Fine	Silt
Centrifuge	44 - 5	Ultra-fine	Clay

The equipment used will depend, in part, on the nature of the geological formation being drilled. In regions where the cuttings are generally large and intact, only shakers need be required. Some geological structures, however, result in higher amounts of fine-sized particles in the drilling fluids and additional procedures, including screening, hydrocyclones, and centrifuges, are required to separate them out.

In the Beaufort Sea/Mackenzie Delta region, where much of the structure consists of poorly lithified sedimentary rock with reactive clays present, the cuttings tend to break down when WBM is used. The particle size is typically about 7-42 µm in diameter, a size range not easily removed by screening devices. In fact, depending upon the well, from 40 to 90% of the solids generated will pass through the shale shaker screens, to be handled by equipment downstream. Over half of this underflow material is removable only by centrifuging.

By reducing the amount of fine, especially ultra-fine, drilled solids in the drilling fluid, a good system for solids control can increase the rate of penetration of the drill bit, especially at levels less than 5% (wt) solids. In addition, bit bearing life can be increased, plastic viscosity of the drilling fluid can be maintained, and good filter-cake properties can be obtained.

Water-based mud returning from a well, containing cuttings and possibly gas from a hydrocarbon-containing formation, is first passed over a vibrating screen, or screens, know as a shale shaker. The cuttings are held on the screen and are discharged to the sea, whereas the drilling fluid and fine cuttings pass through the screen to be treated further. The shaker underflow can then be pumped through desanders, typically a bank of hydrocyclones 30 cm in diameter, and desilters, which consist of a bank of hydrocyclones of smaller diameter (10 cm) than the desanding units. Both these units remove particles smaller than those taken out using the shale shaker.

A mud cleaner, a desander or cyclone placed over a screen, is used for treating a weighted drilling fluid. Solids >74 µm are removed by using a series of screens and centrifugal force. A centrifuge can also be used to remove very fine solids. Finally, a degasser is used to remove gas from the drilling fluid prior to its re-use downhole.

Solids-control equipment can be used in a slightly different manner for an OBM than for a WBM. A solids-control system is still the first stage in the treatment of oiled cuttings. High-efficiency shale shakers are often used to remove as much of the solids as possible before mechanical attrition can wear the particles down in size. A well-operated shale shaker, under favourable conditions, should be capable of removing around 90% (by weight) of the solids. Experience to date has shown that screen meshes that are much finer than those normally used with WBM, can be used with OBM. In the Beaufort Sea, however, even with the use of OBM, much of the solid material from the drill bit is sufficiently small that it will pass through even the fine screens of the shale shaker.

Desanders and desilters have not been used extensively in the wells drilled to date with OBM in the Arctic. The main factors are both environmental and economical, since the discard, or underflow, has a very high oil content. This is not desirable environmentally and, in addition, results in the loss of large amounts of valuable drilling fluid.

To maintain acceptable fluids properties, centrifuges must be used to remove the fine particles the shale shakers are not able to discard. A primary centrifuge is run to recover barite and return it to the active mud system. A secondary centrifuge processes the liquid discarded by the first centrifuge, discarding solid waste and returning the salvaged liquid to the active mud system.

Because of the very fine nature of the solids produced during Arctic drilling, a system such as that described above would generally be the most efficient.[11] The exact layout and operation of solids control equipment (particularly centrifuges) is the preference of the operator and drilling personnel; hence, this description only illustrates a typical system for OBM.

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[11] C. Johanisik, Esso Resources, Calgary, Alberta, personal communication, 1986.

While attaining the goals discussed above, good equipment for solids control should prevent excessively high levels of mud discharge along with rejected cuttings, and reduce the oil load passing to the cuttings cleaning system and, ultimately, to the environment.

Solids (and any associated liquid wastes) discarded from the shale shakers, desanders, desilters and mud cleaners, and centrifuges may be treated in a number of ways. If no cuttings cleaning system is installed, the oily cuttings may be sluiced overboard with sea-water down a disposal chute. If a cleaning system is used, waste from the solids control equipment would be routed through the unit or units. In the latter case, routine solids control systems would be considered as the first stage in the overall treatment and disposal process.

4.3 ARCTIC EXPERIENCE WITH OIL-BASED MUD

In 1985, three offshore Beaufort Sea wells used; Nipterk L-19A, Adgo G-24, and Minuk I-53. Although this represents limited experience, a great deal of information has been obtained on how to use OBM successfully, on how to use solids-control systems with OBM, and on the levels of oil retention on drilling waste. Four main conclusions have been reached to date.

1. Significantly larger cuttings are produced when drilling with OBM versus WBM.

   This observation has been made on all wells to date, to varying degrees. In some cases, particularly in shallower mudstones, cuttings up in the 10-50 mm range have been produced, whereas in past wells in similar geological formations with WBM, no cuttings were produced. The continuous oil-phase mud system inhibits the dispersion normally seen with WBM. Cuttings produced with OBM, when placed in water, will disperse rapidly until only very fine particles are present.

   However, the range of cuttings sizes produced is significant and, in some circumstances, large quantities of very fine cuttings are produced. Efforts to control cuttings size through control of drilling parameters, bit type, bit hydraulics, etc., have been largely ineffective. Some relationship between cuttings size and bit type has been observed, which is believed to be largely a result of formation differences.

2. The design and operation of a solids-control system for OBM drilling fluids is different than that for a typical WBM system.

   The primary piece of solids-control equipment, the shale shaker, plays the most significant role in both removal of solids and in minimizing oil retention. To accomplish this effectively, additional shaker capacity is needed (three shakers rather than the usual two). Derrick "flowline cleaners" are believed to be the most effective type of shaker with a near-horizontal screen profile and horizontal vibration. With this equipment, it is often possible to run up to 250 mesh screens (59 µm per opening). With OBMs, this shaker system with OBM effectively replaces the shakers, desanders, desilters, and mud cleaners used in a WBM system.

Removal of very fine, low-gravity solids is accomplished with a dual-centrifuge system. The primary centrifuge recovers barite, returning it to the active system. The secondary centrifuge processes the overflow from the primary centrifuge, removing the low-gravity solids.

The shaker and dual-centrifuge system has proven to be effective in removing solids from the OBM and build-up of ultra-fine, low-gravity solids in the OBM has not been a problem to date.

3. Oil retention on cuttings, expressed in grams oil per 100 grams dry solids, is dependent on the size of the cuttings produced. Small solids produce high retention; larger particles result in low retention.

   Sieve analyses were conducted on shale shaker overflow from Adgo (9 samples) and Minuk (3 samples to date). Although the data base is not large, the results support this conclusion. Cuttings larger than a four-mesh screen opening (4,760 µm) typically have oil retentions less than 10 g/100 g dry solids. At the other end of the scale, particles between 150 and 500 µm size result in oil retentions in the 20 to 30 g/100 g dry solids range. Similar behaviour was observed at Nipterk with notable differences between centrifuge retentions (fine particles) and shaker overflow (larger cuttings).

   Other parameters appear to have less important effects on oil retention. Most significant is the removal of barite from the mud which lowers the amount of oil per 100 g of dry solids because of the increase in the discarded solids density. Higher temperatures and lower mud rheology (viscosity effects) will lower the oil retention slightly.

4. To date, oil retention in Beaufort Sea drilling has ranged from lows of less than 10 g/100 g dry solids to highs near 35 g/100 g dry solids.

   The range of oil retention achieved (daily weighted average while drilling) and the complete well, weighted-average oil retention for each well is given in Table 4.2

Table 4.2

Oil retention at three offshore Beaufort Sea wells

Well	Oil retention (g oil/100 g dry solids)		
	Minimum	Maximum	Weighted Average
Nipterk L-19A	17.6	37.9	23.6
Adgo G-24	13.8	36.5	22.4
Minuk I-53 (to 2,415 m)	9.7	18.0	14.0

4.4 DEVELOPMENT OF SPECIALIZED TREATMENT AND CLEANING SYSTEMS FOR OIL-BASED MUDS

In the U.K., the initial use of OBM with standard WBM solids-control equipment caused several problems. However, improvements in the solids-control technology, and developments with washing systems for diesel oil-based muds (DBM), have resulted in a decrease in the amount of diesel oil being discharged to the North Sea. Subsequently, specialized cleaning systems were developed, in response to environmental concerns associated with the use of DBM. The systems were installed, along with the routine solids-control equipment, to provide additional clean-up of the cuttings.

The earliest cuttings cleaning systems used for DBM involved only a simple spray-washing process. Other systems included washers that tumbled cuttings and sprayed them with wash solution at the same time, and immersion-wash cleaning systems, in which an aqueous detergent solution was used for washing.

These simple cuttings cleaning systems were not as efficient as was originally envisaged for several reasons, including:

- faster drilling rates than expected have often caused rated capacities of the cleaning equipment to be greatly exceeded;
- the shales so often encountered in the North Sea (and likely in the Arctic) swell and break up in the aqueous wash fluid, thereby reducing the effectiveness of cleaning systems; and,
- rapid contamination of the aqueous wash fluid with oil and fines resulted in the discharge to marine waters of spent wash fluid, containing oil from the cuttings,usually via the cuttings discharge caisson.

Some attempts were made to improve the system by increasing residence times of the cuttings in the wash fluid, and to reduce blockages by installing larger pipes. Another consideration was to use diesel as a replacement for aqueous detergent solutions. The theory was that diesel would reduce blockages of screens and pipes caused by hydrating shales and, when spent, it could be incorporated into the active mud system or incinerated.

Because of the increasing concern over the environmental implications of using DBM (see Section 3), manufacturers of cuttings cleaning equipment worked on ways of improving existing systems. They felt that washing in diesel and incorporating spent diesel into the mud systems would, overall, result in less oil pollution than washing in aqueous detergent solution and dumping the spent solution overboard.[12] Although a typical system, using aqueous detergent solution, cleaned to a level of around 10 g of oil/ 100 g of oil and water-wet cuttings (% wet wt. measured by retorting), the spent wash solution was also dumped overboard, nullifying the effectiveness of the cleaning system. By comparison, diesel wash systems 'cleaned' to residual levels of 15-30% wet weight, but the wash fluid was either recycled to the mud system or was burned (Davies 1984).

In March 1982, the U.K. Department of Energy (DEn) gave notice to North Sea operators that it intended to introduce regulations to control pollution from oil-based mud adhering to cuttings discharged into the sea from U.K. Continental Shelf installations.

Despite all the advantages of OBM, the fluid used to make up the mud, diesel oil, is toxic to many forms of marine flora and fauna. As a result, oil refiners began to develop oils with less toxic bases. A large number of highly refined, white mineral oils became available, with a much smaller percentage of aromatics than diesel. These lower-toxicity oils, or alternative base oils, are mixtures of middle-range aliphatic hydrocarbons which are primarily paraffinic or naphthenic in nature.

The method used to distinguish low-toxicity oil based muds from diesel oil-based muds in the U.K. sector of the North Sea, originated in the non-statutory scheme which the U.K. Government adopted to control the use of toxic chemicals and chemical products offshore. To be acceptable as a low-toxicity drilling fluid, the whole mud and its base oil must have passed an approved toxicity test. As these low-toxicity oil-based muds (LTM) were introduced the requirements to clean the oil cuttings were relaxed. Current legislation in the U.K. states that no further cuttings cleaning equipment is required beyond efficient solids-control equipment, when an LTM is used for either exploration or production drilling in the North Sea. Routine solids-control equipment (shale shakers and centrifuges) has also been considered as sufficient treatment for a number of exploration wells drilled with LTM (Conoco ODC-based) on the Scotian Shelf.

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[12] S.F. Dear, Mobil Oil, Halifax, Nova Scotia, personal communication, 1986.

With the general trend towards the use of LTM in favour of DBM, a number of systems have been developed or proposed specifically for the former. Although they vary widely in complexity they are, in general, less complex than the equivalent systems developed for cuttings contaminated with DBM.

Development of more complex cuttings cleaning equipment has slowed down partly because regulations in the North Sea (as mentioned previously) are less stringent if an LTM is used, and thus could be met by the simpler washing systems. However, several offshore treatment processes have been proposed, such as multistage washing, centrifuge washing, solvent extraction, distillation, and combustion.

One of the major reasons for the development of sophisticated cuttings treatment systems has been economic; to recover expensive drilling fluids for recovery to the active mud system. This recovery would be particularly applicable during the production phase, when many wells are drilled and the cost/benefit analysis of a cuttings cleaning system is more attractive than during single-well exploration drilling. The discharge of cuttings with a much lower oil content is also more acceptable environmentally.

5.0 TREATMENT OPTIONS

5.1 GENERAL

The drill cuttings removed by the solids-control systems discussed in the previous section can be discharged directly or can undergo further treatment, if necessary. When using an OBM, additional treatment options may be considered to reduce the oil adhering to the cuttings, either to minimize the environmental risk, or to recover the oil itself for reuse, or both.

This section outlines in detail the various specialized systems which have been developed for cleaning cuttings contaminated with OBM, their stage of development, and the strengths and weaknesses of each.

The systems have been grouped into four, general categories: spray wash; immersion wash; thermal systems; and stabilization (solidifier) systems. Each of these could be engaged after the routine solids-control system.

5.2 TREATMENT SYSTEMS

Table 5.1 lists the treatment systems reviewed, whereas Tables 5.2 and 5.3 summarize the major features. More detailed information is presented in Appendix 1.

5.2.1 Spray Wash Systems

These systems were developed by manufacturers of solids-control equipment and use standard items of solids-control equipment in their construction.

Cuttings from all or part of the solids-control equipment are sluiced to a vibrating screen unit. As oversize cuttings travel along the screen, they are first sprayed with wash fluid (which may be either diesel or aqueous-based) and are then allowed to drain for the remainder of the screen.

Undersized cuttings fall through the screen mesh along with the wash fluid. In some cases the latter is treated in a desilting cyclone or in a centrifuge to remove some of the undersized material. Generally, the separated cuttings are then discharged down a caisson where any remaining free oil on the water surface may be removed by skimming.

Once the wash fluid becomes unacceptably contaminated with oil and fines (the rate at which this occurs will depend primarily on drilling rate and on the screen size of the cuttings cleaning unit), it must be disposed of in some manner. It is claimed that diesel-based wash fluid could be re-incorporated into the active mud system. Spent aqueous wash fluid is usually discharged overboard, often down the cuttings disposal

Table 5.1

Treatment systems available or under development for the cleaning of cuttings

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Spray Wash Systems

1. NL Baroid (UK) Ltd. Neat System
2. Modified "NEAT" System used on Valhall

Immersion Wash Systems

3. NL Baroid (UK) Ltd. Cuttings Processor
4. Dresser Magcobar/Mobil Oil Corp. MPA Systems
5. Drexel Equipment (UK) Ltd. Cuttings Wash System
6. NL Baroid CW4 Separate System
7. Thomas Broadbent and Sons Ltd. Base Oil Centrifuge Wash System
8. Dresser Swaco Wash Drum/Centrifuge System
9. Drexel Norway Wash Drum/Centrifuge System
10. Drexel Equipment (UK) Ltd. Two Stage Wash System
11. Drexel Equipment (UK) Ltd. Three Stage Wash System
12. Thomas Broadbent and Sons Ltd. Aqueous Centrifuge Wash System
13. Sweco/FIS Trichloroethane Wash System
14. Critical Fluid Systems Inc. Supercritical Fluid Leaching Process

Distillation Systems

15. Hughes Drilling Fluids CREW System
16. Dresser Swaco Vibrating Bed Cuttings Drier
17. Oiltools Cuttings Disposal System
18. Star Industries "Volitilizer" Incineration Process

Combustion Systems

19. Hamjern A/S Fluidized Bed Combustion System
20. West's Prochem/Walsh Prochem Fluotherm Fluidized Bed Combustor
21. Standard Incinerators

Stabilization Systems

22. Buchen and Leo GMB# LECO Quicklime Stabilization System
23. Standard Quicklime Stabilization System
24. Envirite Solidifer

Miscellaneous Untested Systems

25. Mobil Oil Corporation Briquetting System
26. Thule Ultrasonics Assisted Wash System
27. Chromalloy Delta Mud Sluiceway System
28. Mud tools/FIS Trichloroethane Centrifuge Wash System

Table 5.2

Summary of cuttings treatment systems based on washing processes

Type of system	Manufacturer/ ref. no.	Stage of development/ testing	Method of washing	Wash fluids used	Method of separating cuttings	Method of removing oil and fines from wash fluid	Oil retained on cuttings (% wet wt)	Fate of removed fines	Fate of recovered oil	Other comments
Spray Wash	-N.L. Baroid, NEAT (#1) -N.L. Baroid, Modified (#2)	Systems field tested on rigs	Spray wash on shaker screens	Aqueous (#1) or diesel wash (#2)	Shaker screens	Sluiceway/ caisson for oil recovery	5-12 (#1), 8 (#2)	Discharged overboard	Spent diesel & any oil recovered for sluiceway/caisson recycled to mud	Poor cleaning; not likely to be used in North Sea
Immersion wash, first generation	-Baroid cuttings processor (#3) -Dresser/Magco. M.P.A. (#4) -Drex./Sweco cuttings wash (#5)	Systems field tested on rigs	Immersion wash, 1 stage	Aqueous or diesel wash	Shaker screens	Cyclones and/or centrifuges	7-12 (#3) 7-20 (#4) 6-28 (#5)	Discharged or incinerated	Recycled or incinerated	Poor cleaning; spent ageous wash fluid discharged overboard(#3)
Wash system with regenerable wash fluid	-Baroid CW4 (#6)	Concept tested offshore by modifying a first-generation system	Cuttings sluiced from solids control to cleaning system shaker	2 batches of aqueous detergent solution (1 working, 1 regenerating)	Vibrating screens (shaker)	Optional cyclones and centrifuges. Spent fluid passes to settling tank	?	Settled oily fines sludge claimed recycled to active mud system	Settled oily fines sludge claimed recycled to active mud system	Once sludge is recycled to the mud remaining fluid is topped up with detergent for re-use
Base oil centrifuge wash system	-Broad. Base Oil centrifuge wash (#7)	Broad. system tested onshore and pilot tested offshore	Immersion in agitated tank (+)	Low toxicity mud base oil	Decanting centrifuge	High speed decanting centrifuge in 1 case	<10	Combusted		?
Aqueous detergent wash drum system	-Dress. wash drum/ centrifuge (#8)	Tested at full scale onshore	Cuttings are tumbled with wash fluid in wash drum	Aqueous detergent solution	Wash drum (drying section)	2-phase decanting centrifuge then 3-phase disc stack centrifuge	1-20	Discharged overboard	Claimed recycled to active mud system	
Aqueous detergent wash drum system	-Drex. wash drum centrifuge (#9)	Tested at full scale onshore	Optional immersion in agitated tank then tumbled in wash drum	Aqueous detergent solution (see also other comments)	Wash drum (drying section)	Emulsion breaker and 3-phase decanting centrifuge then optional band	5	Discharged overboard or combusted	Claimed recycled to active mud system	LTM base oil wash fluid could also be used to treat LTM cuttings

Table 5.2 (continued)

Type of system	Manufacturer/ ref. no.	Stages of development/ testing	Method of washing	Wash fluids used	Method of separating cuttings	Method of removing oil and fines from wash fluid	Oil retained on cuttings (% wet wt)	Fate of removed fines	Fate of recovered oil	Other comments
Multistage wash system	-Drex. U.K. 2-stage wash (#10); -Drex. U.K. 3-stage wash (#11)	Prototype 3 stage system tested offshore	Immersion in agitated tanks	1 diesel wash followed by 1 or 2 sea water wash(es)	Vibrating screens	Cyclones and centrifuges (one 3-phase centrifuge)	<5	Discharged overboard	Claimed recycled to active mud system	Process basically comprises 2 or 3 single-stage immersion washes in series
Aqueous detergent centrifuge wash system	-Broad aqueous centrifuge wash (#12)	Tested at pilot scale onshore and offshore	Cuttings sluiced from solids control into centrifuge where they are sprayed	Aqueous detergent solution	Decanting centrifuge	Flocculant injection and 3-phase high-speed decanting centrifuge	3-7	Combusted	Claimed recycled to active mud system	
Chlorinated solvent wash systems	-SWECO/FIS Trichloroethane (#13)	Tested at pilot scale onshore	Either immersion in agitated tank or sluiced from solids control to cuttings cleaning system	Trichlorethane	Vibrating screens (DEM)? system or centrifuge (LTH system)?	Centrifuge and batch still	<1-3	Fines from centrifuge discharged overboard recycled with oil to mud		Any first-generation system could have been modified by manufacturer for use with trichlorethane
Supercritical fluid leaching process	-CFS supercritical fluid (#14)	Conceptual. Bench tests have been carried out for DEM cuttings	2 immersion washes	Diesel then supercritical CO_2 (or freon or propane	Wash fluids are allowed to drain from leaching vessel	CO_2 flashed off in 3 stages of separation	<1	Fines stay with recovered mud (or could be centrifuged)		

Table 5.2 (continued)

Type of system	Manufacturer/ ref. no.	Stages of development/ testing	Method of washing	Wash fluids used	Method of separating cuttings	Method of removing oil and fines from wash fluid	Oil retained on cuttings (% wet wt)	Fate of removed fines	Fate of recovered oil	Other comments
Ultrasonics assisted wash process	-Concept	Bench tests carried out	Immersion in agitated tank then pumped through ultrasonic vibrator	Aqueous solution containing shear-sensitive detergent	Cuttings allowed to settle (in settling tank)	Oil floats to surface, fines sink in settling tank	?	Cuttings, fines and used wash fluid discharged overboard	?	Wash fluid used on a once-through basis
Wash system with heated wash fluid	-Concept	Concept not thought to have been tested	Immersion in heated a agitated tank	Aqueous detergent heated agitated tank	Probably a vibrating screen	Probably cyclones and centrifuge	?	Probably discharged overboard	?	In theory hot wash fluid should allow easier oil removal from cuttings

Table 5.3

Summary of cutting treatment systems based on thermal or stabilization processes

Type of system	Manufacturer/ ref. no.	Stages of development	Brief description of system	Source of heat	Surge/batch storage vessel specified	Oil retained on cuttings (% wet wt)	Fate of recovered oil	Other comments
DISTILLATION SYSTEMS								
Batch vacuum distillation system	-Hughes/Crew system (#15)	Tested at full scale onshore	Cuttings fed into retort via grinding blades and heated to 350°C at -0.96 bar a. Vapours pass through heated cyclone (fines removal) then condenser (oil recovery). All cuttings are discharged.	Electricity	Required	<1	Claimed recycled to active mud system	Cycle time 30 minutes (20) min. processing plus load/unload
Vibrated bed drier system	-Dress. vibrating drier (#16)	Tested at full scale onshore	Cuttings pass across vibrated bed. Hot air blown up through bed carries off oil, water and fines. These pass through cyclone and scrubber (fines removal and oil condensing). Oil and water then separated. Water and all solids are discharged.	Part of the recovered oil powers air-heating burner	Yes	<1	Claimed recycled to active mud system	
Two stage distillation system	-Oil tools disposal (#17)	Tested at full scale on shore	Cuttings are carried down a heated tube. Some of the vapours are distilled off to fuel heater. Cuttings then pass through a second similar tube. Cleaned cuttings are cooled with seawater and discharged.	Oil removed from cuttings	No	<1	None recovered	
Star volitilizer (#18)	Vacuum distillation	Prototype tested	Cuttings are carried continuously, through an insulated heated tube where oil is incinerated at 800°C	Electricity	Required	<1	Combusted	

Table 5.3 (continued)

Type of system	Manufacturer/ ref. no.	Stages of development	Brief description of system	Source of heat	Surge/batch storage vessel specified	Oil retained on cuttings (% wet wt)	Fate of recovered oil	Other comments
COMBUSTION SYSTEMS								
Fluidized bed combustion	-Hamjern fluidized bed (#19) -Prochem. fluidized bed	Tested at pilot scale onshore	Cuttings pass through bed. Fluidized air is blown up through bed and oil on cuttings is combusted. Flue gasses pass through cyclone and in one case a quench/baffle chamber for fines removal. All cuttings are discharged.	Oil on cuttings	No	<1	None recovered (combusted)	One system considered for diesel cuttings treatment on UK sector platform
STABILIZATION SYSTEMS								
Stabilization system for treating cuttings onshore	-Leco/Quicklime stabilization (#21) -Standard Quicklime stabilization (#22)	Tested onshore	Cuttings pass through feed hopper into 2-stage mixing reaction vessel with CaO added. Mixture then slowly conveyed to discharge point. Emerges as dry, hydrophobic product.	Yes		N/A	As above	Other systems could be adapted

caisson, to allow any free oil to be skimmed off the surface of the water and recovered.

5.2.2 Immersion Wash Systems

Cuttings are sluiced from the solids-control system to an agitated tank containing diesel or aqueous-based wash fluid. The resulting slurry is then pumped over vibrating screens. Oversized cuttings are discharged whereas undersized cuttings flow back to the agitated tank. Once the wash fluid becomes unacceptably contaminated with fines (and oil), it must be disposed of in a manner similar to that used for spray wash systems. Generally, there is no net gain in reducing total oil discharges to the environment.

More advanced systems include wash fluid treatment using cyclones or centrifuges. Diesel wash fluid, and any remaining solids, are recycled to the wash tank. Once spent, the diesel is either recycled to the active mud system or pumped to a tank prior to disposal by burning in oil test burners.

Immersion wash systems can also incorporate multi-stage washes (diesel/sea-water or diesel/sea-water/sea-water). After each stage, separated wash fluid is recycled. A three-phase decanting centrifuge is used at the final stage of the treatment system to remove dispersed oil in the sea water wash fluid and to recycle it to the first stage (diesel) wash tank, or to the active mud system, or to both.

Another group classified as immersion wash systems are solvent extraction units. Cuttings are treated in solvents, (e.g., trichloroethane or liquid CO_2) which, having considerably greater oil-removal properties than aqueous detergents, give much improved cleaning performance. Because solvent costs are relatively high, it is logical that these systems should incorporate cleaning and recovery steps.

A number of wash systems have been developed specifically for treating low-toxicity mud-contaminated cuttings. They include a simple sluiceway system, base-oil centrifuge wash systems, and wash-drum centrifuge systems.

The sluiceway incorporates a spray wash (with sea-water) of the cuttings as they fall from the solids-control equipment, through a caisson to the receiving water. Any oil released will form a layer at the sea surface and is recovered by a skimmer.

In the base-oil centrifuge wash system, cuttings are washed in a tank containing base oil, and then are pumped into a two-phase decanting centrifuge which yields dried cuttings and base oil to be recycled back to the wash tank.

The wash-drum centrifuge systems involve washing the cuttings with aqueous fluid in a wash drum (which rotates at a much slower rate than a centrifuge) in two stages, to remove fines and oil. The cuttings are discharged and the dirty wash fluid is pumped to a two-phase decanting centrifuge, to remove fines, and then to a three-phase centrifuge to remove ultra-fines. Cleaned wash fluid is recycled to the drum and oil is returned to the mud system.

5.2.3 Thermal System

These systems involved distillation, combustion, or a combination of the two, to drive the oil and water from the cuttings, using heat.

In batch vacuum-distillation systems, cuttings are stored in a buffer storage tank. At the commencement of the cycle a batch is fed into the retort barrel of the unit through grinding blades. The ground cuttings are heated under a vacuum which causes oil and water to distill off. Any fines generated are removed in a heated cyclone, after which the vapours are condensed and recycled to the active mud system. At the end of the distillation cycle, all solids are discharged overboard.

In a second type of distillation system, basically a two-stage process, cuttings pass through a surge tank and are transported down a heat tube by an internal auger. Some of the vapours distill off and are collected and ignited with air to heat the heat tube for final hydrocarbon recovery (these vapours are also recycled and ignited). The treated cuttings are then cooled with sea-water and are discharged from the bottom of the unit.

In vibrator bed systems, cuttings pass through a surge hopper and are conveyed across the drier bed, with heated air blown upward through the material. The hot air drives oil and water from the cuttings, and the gaseous stream then exits at the top of the drier, along with some fine cuttings. The fine cuttings are removed by a cyclone and scrubber, which also condenses the oil and water. Oil and water are separated in an oil/water separator. Some of the oil may be used to power the air furnace; the remainder (it is claimed), may be recycled to the active mud system although this recycling will depend on the actual state of the recovered oil. All solids and the de-oiled water are discharged overboard.

5.2.4 Stabilization Systems

These systems basically stabilize the oil on cuttings rather than removing it. In the Leco system, a specially-treated quicklime (CaO) is used to produce a product suitable for use as a filler for road construction material. Following the Amoco Cadiz incident, oil beach sands were stabilized with a similar system, using standard grades of industrial quicklime. Recently, studies have been reported on a quicklime stabilization process incorporating pulverized fly ash (PFA) and oiled beach sands.

5.3 SPECIALIZED CUTTINGS CLEANING SYSTEMS: POINTS TO CONSIDER

It is important to recognize the stages of development of the various systems (see Tables 5.2 and 5.3). The larger the scale and the greater the periods of testing that prototype units have undergone, the greater the chances that unforeseen problems will have been ironed out by the time a full-scale system is installed. Unfortunately, few systems have undergone full-scale testing, primarily because of the expense, both to operators and manufacturers.

Several general points, described below, should be considered when reviewing a cuttings cleaning systems.

5.3.1 Capacity

The relatively poor cleaning performance of early systems resulted from several problems, many of which related to the capacity of the system. One problem was that the peak cuttings flowrate expected from a well was often underestimated, partly because of faster rates of penetration (ROP) from the use of OBM. In addition, expected cuttings flowrates may have been based on an averaged hourly flow, rather than the maximum instantaneous ROP. Use of the latter will minimize the risk of under-design of the cuttings cleaning system.

A second problem was that the manufacturers of cuttings cleaning equipment had sometimes made optimistic assumptions and statements concerning the capabilities of all, or part of, a system. For example, if separation data for screens, cyclones, and centrifuges are based on tests carried out with water, their solids removal efficiency will be reduced when using diesel or low-toxicity base oil, or an oil/water or water/oil emulsion.

Some manufacturers of thermal systems have neglected to stress the importance of oil and water loadings on the cuttings with respect to the capacity of their equipment. Some formations drilled can contain up to 40% by weight of interstitial water, which would reduce either the capacity, or the cleaning performance, of a thermal system. (Water has a particularly high latent heat of vaporization which poses a high heat drain.) An operator encountering such a water content would be advised, if contemplating thermal cuttings processing, to consider combustion systems where extra fuel can be added with relative ease, in favour of distillation systems.

In general, the capacity of a wash system will not be nearly as dependent on oil and water loadings on cuttings as a thermal system.

5.3.2 Cleaning Performance

The system selected will depend, to a large extent, on the discharge limits and other controls imposed on an operator. Thermal and solvent extraction systems should provide considerably better cleaning performance than aqueous or base-oil wash systems. A thermal system would probably reduce residual oil on cuttings to less than 1 g oil/100 g dry (retorted) cuttings whereas some of the better wash systems should be capable of refinement to produce discharged cuttings having less than 10 g oil/100 g dry (retorted cuttings).

A few lessons can be learned from the performance of early systems. Immersion wash systems generally give better cleaning performance than spray washers because of a more efficient and longer contact period. The sluiceway and caisson arrangements used for secondary oil recovery in many of these systems often did not work as originally envisaged. The high flowrates of sea-water used to sluice the cuttings overboard caused much of the free oil released from the cuttings to be entrained and thus to be discharged with the cuttings and sluice water.

With more recently developed wash systems any test data supplied by the manufacturer should be reviewed to ensure that all discharges are accounted for. A full-system mass balance is the ideal way to present test data.

5.3.3 Size, Weight, and Power Requirements

The importance of these factors will vary, depending on the size of platform or rig on which a system is to be installed. Because the trend is towards smaller platforms and floating production systems, preference likely would be given to compact cleaning systems. The ability of a system to be broken into components for retro-fit on an existing installation, or fitting into confined spaces, would also be an advantage.

In general, the wash systems and solvent extraction systems provide greater cuttings throughput per unit tonne, square metre, and kilowatt of power, than an equivalent thermal process, at the expense of reduced cleaning efficiency. It is also worth noting that a continuous system is, overall, more efficient with respect to space, weight, and energy, compared to a batch process.

5.3.4 Chemical Requirements

Most wash systems require a continuous supply of chemicals for efficient operation. The stock of special chemicals (e.g., solvents) that can be maintained at a drilling site may be limited by weight, space, and logistics (e.g., supply) considerations. Where lack of space is a particular problem, it would be better to use a chemical that is also used elsewhere (e.g., low-toxicity base oil). Solvents such as trichloroethane and liquid CO_2 may impose a significant cost if losses are high.

5.3.5 Operator Requirements

The need for full-time operators should be minimized on smaller drilling platforms, because accommodation is likely to be limited. In this case, a system with a high degree of automation and low maintenance requirements would likely be preferable. Most of the thermal systems are claimed to fall into this category.

5.3.6 Efficiency of the Solids-Control System

Efficiency is particularly important where distillation systems are employed. A sudden surge of cuttings and whole mud would severely reduce the throughput and cleaning efficiency of such systems. However, a slug of whole mud entering a wash system using aqueous wash fluid might also create problems, because the emulsifiers in the mud will promote a strong, and difficult-to-break, emulsion.

5.3.7 Choice of Wash Fluid: Aqueous or Base Oil

In theory, an aqueous detergent solution should provide better cleaning performance in a system than a base oil. However, many geological formations contain sections of highly hydratable clay and shale materials (one of the prime reasons for using OBM) which rapidly swell and break up in aqueous wash fluids. This break-up generates a large proportion of fines which must be separated from the fluid. The presence of fines increases the viscosity of the wash fluid thus making separation more difficult. This "catch 22" situation is made worse in many cases when the oil, which has been separated from cuttings forms an emulsion with the water. The formation of this emulsion is promoted by the wash fluid detergent as well as by some of the mud additives carried over with the cuttings.

Although some systems use flocculants to remove fines and emulsified oil, the use of a cuttings cleaning system employing aqueous wash fluid would be less effective in formations where hydratable materials (such as those frequently found in the Beaufort) are likely to be encountered in significant amounts. If such a system were used, large amounts of contaminated aqueous wash fluids would be generated, which would have to be disposed of in some way.

5.3.8 Oil Recycled to the Mud System

Some systems claim that at least some components of the mud can be removed and recycled to the active mud system. In practice, it is likely that the recycle stream will have suffered emulsification with water (from aqueous wash fluids), fines contamination (from virtually any system), or thermal degradation (from distillation systems). The recycling of oil contaminated with fines is particularly bad practice because it is the fine cuttings that have the most detrimental effect on the properties and performance of the mud. It should be recognized that the preference of most operators is to be able to recycle and reclaim valuable liquids. A system which merely discharges the oil is less desirable than one which can help reduce operating costs.

5.3.9 Safety Aspects

Wash systems have the advantage over thermal systems in that they run "cold" and hence operate with a lower risk of fire and explosion. Restrictions governing the location of such units on a drill unit should be less severe than for a thermal system. Some operator health risks also exist from toxic vapours from the use of thermal systems, as well as from wash systems using more exotic wash fluids such as trichloroethane.

5.3.10 Erosion Problems in Centrifugal Systems

It is not yet know whether treating the whole range of cuttings in centrifuges will pose a long-term erosion problem. Ceramic tiling or hard-facing is used in most cases in an attempt to combat this.

5.3.11 Corrosion Problems in Thermal Systems

Where water and chlorides are present in the feed to a thermal system that is operating at high temperatures, corrosion and agglomeration problems may occur. In addition, some thermal systems may reach a temperature where fusion of cuttings is possible. This could cause major problems if the unit encountered a surge, which would tend to cool the process, or if the unit had to be shut down rapidly for any reason. As yet, there are no data to confirm or refute this.

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6.0 EVALUATION MATRICES

6.1 GENERAL

The information in the preceding section (along with other review reports such as Thomas et al. 1984; Milne and Greene 1985) was presented in order to assist operators and regulatory agencies in deciding which treatment and disposal option to select for drill cuttings contaminated with OBM.

The different treatment and disposal options that could be available include:

For Offshore Wells:

- routine solids-control equipment with discharge of cuttings to marine waters;
- routine solids-control equipment plus additional treatment system(s) (spray wash, immersion wash, distillation,or combustion), with disposal of treated cuttings to marine waters; or,
- routine solids-control equipment with transport of cuttings to shore for disposal by burial (with or without cuttings stabilization) or by incineration and burial of the ash.

For Onshore Wells:

- routine solids-control equipment and disposal of cuttings into landfill sites (sumps or spreading); or,
- routine solids-control equipment, with incineration of cuttings and disposal of ash into landfill sites.

In selecting a treatment system and subsequent disposal method, a number of factors need to be considered which include:

- the engineering and logistical considerations of each treatment system (Section 6.2);
- environmental considerations related to the treatment and disposal option (Section 6.3); and,
- cost/benefit considerations of each treatment and disposal option (Section 6.4).

For each of the these factors, a ratings system was devised to enable comparisons to be made between the different treatment systems. These ratings are defined in the following sections and are used to produce the appropriate matrices.

TABLE 6.1

Engineering and logistical considerations

REGION OF ACTIVITY: Offshore **DISPOSAL OPTION:** Non-Specific

BASE OIL USED: Non-Specific

Issues / Treatment Systems	Capacity (a)	Cleaning Performance	Size (e)	Weight (h)	Power Requirements	Process Supplies Requirements	Safety Consider-ations (k)	Manpower Require-ments (l)	Vessel Support (m)	Shorebase Support (n)
A. ROUTINE SOLIDS CONTROL	4	4	1	1	1	1	2	2	1	1
B. SPRAY WASH										
1. N.L. Baroid, Neat	1	4(c)	1	1	1	3	1/2	2	2(4)	2
2. N.L. Modified Neat	3	4(c)	1	?	2	3	1/2	2	2(4)	2
C. IMMERSION WASH										
3. Baroid Cuttings Processor	3	2-3	1	1	1	3	1/2	2	2(4)	2
4. Dress./Magco. M.P.A.	3	2-3	4(f)	4	4	2	2	4	2(4)	3
5. Drex. Cuttings Wash	2	3-4	1	1	2	2	2	2	2(4)	2
6. Baroid CW4	3	?	2	2	2	3	1	2	2(4)	2
7. Broad. Base Oil Centrif. Wash	4	2	3	4	3	2	2	2	2(4)	2
8. Dress. Wash Drum/Centrif.	3	3	1	1	3	3	1	2	2(4)	2
9. Drex. Wash Drum Centrifuge	3	2	1	1	2	2/3(j)	1/2	2	2(4)	2
10. Drex. U.K. Two-Stage Wash	2	2	3	2	3	2	2	2	2(4)	2
11. Drex. U.K. Three-Stage Wash	2	2	3	2	3	2	2	2	2(4)	2
12. Broad.Aqueous Centrif. Wash	4	2(d)	3	3	3	3	1	2	2(4)	2
13. Sweco/Fis Trichloroethane	2	1-2	2	3	3	4	3	3	2(4)	2
14. CFS Supercritical Fluid	1	1	2	1	3	4	4	4	2(4)	3
D. THERMAL SYSTEMS	(b)									
D1. <u>Distillation</u>										
15. Hughes/Crew System	1	1	3	2	3	1	4	1/4	2(4)	2
16. Dress. Vibrating Drier	1	1	4	2	4	1	4	3	2(4)	2
17. Oil-Tools Disposal	1	1	3	1	2(i)	1	4	3	2(4)	2
18. Star Volitilizer	1	1	1	1	2	1	4	3	2(4)	2
D2. <u>Combustion</u>										
19. Hamjern Fluidized Bed	2	1	3	3	3	1	4	1/3	2(4)	2
20. Prochem. Fluidized Bed	2	1	4	3	3	1	4	3	2(4)	2
21. Incinerators										
E. ONSHORE STABILIZATION										
22. Leco/Quicklime Stabilization	4	-	4(g)	2	1	3	3	2	(4)	2
23. Standard Quicklime Stabilization	4	-	4	2	1	3	3	2	(4)	2
24. Solidifiers	1	-	1	1	1	3	1	2	(4)	2

Note: (a) - (n) follow table

NOTES TO TABLE 6.1

(a) In the case where multiples of the principal treatment were configured together (e.g., tandem arrangements), the largest common configuration was rated for capacity.

(b) Performance of thermal systems is highly influenced by the fluid loading on the cuttings input. Thus, ratings are based on the capacity of processing a standard cuttings stream: 25% wt. oil, 10% wt. water, and 65% wt. inorganic material.

With a potential for greater fluid loading, combustion processing, as compared to distillation, is more efficient.

In general, the capacity of a wash system will not be nearly as dependent on the oil and water loadings on cuttings as a thermal system.

(c) Caisson systems are thought to be ineffective for oil recovery. Much of the oil released from the cuttings, and separated out in the caisson, gets entrained in the caisson discharge. Thus, most of the oil removed from the cuttings is discharged into the sea.

(d) Broadbent Aqueous Wash cleaning performance specifications are based on results from a pilot test only (processing 2.2 tonnes/hr). The other specification categories address the largest configuration, e.g., 22 tonnes/hr treatment system.

(e) The system dimensions, plus any probable tank storage requirements, were obtained from reference material. Tank volumes were converted to m^3 and were tallied with the system size. This total was then rated.

(f) The M.P.A. system includes the complete solids-control system, which is reflected in the ratings found in the size, weight, and power-requirements categories.

(g) Reference material only, provided the base dimensions of this system; a height was assumed at 2 m.

(h) Where possible, the net weight was used to rate a system.

(i) The Oil-tools system draws 300 kW during start-up and then operates 85 kW. The operating power was used in rating the system.

(j) This wash system has optional wash fluids, e.g., aqueous detergent solution or base-oil wash fluid.

(k) The systems rated by a "1 or 2" have a variability depending on the wash fluids used. Base-oil fluids have fumes to consider whereas aqueous solutions are relatively benign.

(l) Systems rated by more than one number are claimed by the manufacturer to be automatic, requiring few personnel. However, the systems remain to be field tested and thus would require, initially, a dedicated crew of trouble-shooters.

(m) The open numbers refer to marine discharge as a disposal option; those in parentheses are for land disposal options.

(n) Shorebase support is for both marine and land disposal options.

6.2 ENGINEERING AND LOGISTICAL CONSIDERATIONS

Each treatment system was rated with respect to the following categories:

- processing capacity
- cleaning performance
- size, weight, and power requirements
- process supplies
- safety concerns
- personnel requirements
- vessel support requirements
- shorebase support requirements.

The different ratings (1, 2, 3, or 4) for each category are presented in the matrix (Table 6.1). The rating of the engineering considerations of each treatment system was considered to be independent of the base oil used. Descriptions of the rating system for each category follows.

6.2.1 Processing Capacity

Processing capacity refers to the amount of cuttings from the solids-control equipment that can be handled by a particular treatment system. These data should be compared to the average hourly solids generation of 0.5-10 tonnes for Arctic wells. The lower range is from smaller hole sections (7-8") at a slow rate of penetration (ROP) (5-6 m/hr), where the upper range of solids generated would be from large-diameter holes (17.5").

Rating scale	Criteria
1	1 - 5 tonnes/hr
2	5 - 10 tonnes/hr
3	10 - 20 tonnes/hr
4	> 20 tonnes/hr

6.2.2 Cleaning Performance

In discussing cleaning performance of different cuttings treatment systems, it is important to realize that there are several ways of expressing the amount of oil that is retained on the waste material discharged from cuttings treatment systems. Simply expressing oil on cuttings as a % wet-weight (w/w) retained on cuttings is not particularly meaningful as further clarification is required. Several terms have been developed for discussing the oil retention on cleaned cuttings, including:

1. g oil/100 g effluent (% wet weight) = weight of oil associated with 100 g of (oil + water + solids)

2. g oil/100 g wet cuttings (% wet weight) = weight of oil associated with 100 g of (water + solids)

3. g oil/100 g dry cuttings = weight of oil associated with 100 g of dry solids.

Systems were rated by the amount of oil retained on the cuttings after treatment, in percent wet weight.

Rating scale	Criteria
1	< 1% wet weight
2	1 - 5% wet weight
3	5 - 10% wet weight
4	> 10% wet weight

6.2.3 Size, Weight, and Power Requirements

The importance of these factors varies depending on the size of the rig or platform on which the system is to be installed. Compact systems should be more attractive. Flexibility of an installation is important in terms of retrofitting the system to another rig or fitting the system into tight confines.

Wash systems and solvent extraction systems provide greater cuttings throughput/unit tonne, square metre, and kilowatt, compared to an equivalent thermal system. Thermal systems, however, generally have better cleaning efficiencies. A continuous system is more efficient with respect to space, weight, and energy, than a batch process.

Wash systems require a continuous supply of chemicals for their efficient operation; thus extra space and weight are a consideration. When storage space is limited, a generic consumable is attractive (e.g., base-oil wash fluid).

	Criteria		
Rating Scale	Size (m^3)	Weight (tonnes)	Power requirements (kW)
1	<50	<25	<25
2	50 - 100	25 - 50	25 - 100
3	100 - 500	50 - 100	100 - 500
4	>500	>100	>500

6.2.4 Process Supplies

If a consumable is used in the treatment, the demand and nature of the supply must be considered. This may range from generic supplies, as in base-oil wash fluid, to specialized fluids used in an extracting process (e.g., trichloroethane).

Rating scale	Criteria
1	Negligible consumables (i.e., incineration or distillation processes)
2	Generic consumables (i.e., base-oil wash fluids)
3	Treatment specific supplies, with medium-to-high demand (e.g., wash fluid surfactants)
4	Exotic supplies (i.e., closed systems with low losses; trichloroethane, CO_2, and Freon).

6.2.5 Safety Concerns

Potential hazards relating to the rig, to personnel, and to the environment are considered. Rig hazards include fire and explosion risks. Hazards to personnel include contamination in the working environment and the temperatures that may be encountered. Atmospheric pollution around the rig is also considered.

Rating scale	Criteria
1	Cool system; aqueous fluids
2	Cool system; fumes and dermatitis; health hazards from fumes
3	Hot system; health hazards from fumes
4	Fire and explosion hazard; health hazards from fumes

6.2.6 Personnel Requirements

Systems that do not require specialized personnel, especially on offshore platforms in which accommodation is limited, are preferable to those requiring dedicated personnel.

Rating scale	Criteria
1	Highly automated process, with low maintenance requirements
2	Process supervised by rig personnel; skilled maintenance required
3	Process requires dedicated supervision and operation; specialized maintenance required
4	Process requires full-time crew for operations and maintenance.

6.2.7 Vessel Support Requirements

Rating scale	Criteria
1	No vessel required
2	Slight increase in vessel movement required
3	Increased vessel movement, but not enough to require additional dedicated vessel
4	Dedicated vessel required to store and carry waste away for further disposal; dedicated support equipment and process required.

6.2.8 Shorebase Support Requirements

Rating scale	Criteria
1	No support required
2	Some additional support required
3	Increased logistics, but without increased equipment
4	Dedicated equipment and personnel to support process.

6.3 ENVIRONMENTAL CONSIDERATIONS

The environmental concerns associated with the discharge of cuttings into marine waters, disposal in landfills, or by incinerations were independently assessed for each treatment and cleaning system.

6.3.1 Offshore Disposal Options

A) Base oil used. Unlike the engineering and logistics considerations, environmental effects may differ with the type of base oil used.

Most of the literature on environmental effects refers to information related to diesel-based muds, with only the more recent reports evaluating the low-toxicity formulations. Few data are available on oils in the 5-20% aromatic range. Because most of the available data and concerns relate to the aromatic content of the base oil, the environmental matrices consider the low aromatic base oils (<1% aromatics, Brandes IR method) and diesel (>20% aromatics, Brandes IR method). It is assumed that the environmental effects of other base oils will fall somewhere between these two extremes.

It must be emphasized that the concerns related to the differences in the effects of cuttings between low aromatic base oils and diesel base oils are based on the short-term (96-hr LC_{50}) toxicity of the base oils. Although it seems reasonable that there may be some difference between the environmental effects of the cuttings from the two types of base oils, there are three potential difficulties with this assumption. First, no field studies have been done where it is possible to make a direct comparison of the effects of cuttings discharged using the two types of base oils. Secondly, organic enrichment and smothering of the sediments by the oiled cuttings may override the 96-hr LC_{50} toxicity effects in the environment and there may be little actual difference in effects of the two types of muds (Addy et al. 1984). Thirdly, it is difficult to extrapolate the results of studies of multi-well production situations in the U.K. to single exploratory wells in Canada.

Furthermore, whereas low-toxicity base oils can vary considerable in their short-term (96 hr) toxicity, the toxicity of the drilling muds made up with them is quite similar (Blackman et al. 1983).

B) Geographical location. The environmental effects of oil-contaminated cuttings discharged to Arctic marine waters are a function of the ultimate fate of the cuttings themselves and the biological resources present. The dispersion/location of cuttings (see Section 3) is influenced by wave-induced mixing, which in turn, is a function of water depth; by ice-scouring, also a function of water depth; by suspended sediment depositions; and tidal currents.

In shallow water, and particularly along the Mackenzie Delta, waves and ice (especially during break-up) will be major forces affecting sediment/cuttings movement, although it must be remembered that there is a seasonal component to this. For example, there is likely to be a minimal disturbance of bottom material during the winter periods of permanent ice cover but the cuttings can be expected to be affected by ice moment and by wave action during the break-up and open-water period. It is assumed that the fate of cuttings discharged under the ice in the shallow Beaufort Sea area will be relatively similar to that of those discharged in greater than about 20 m of water during the open-water.

Mixing and movement of bottom sediment material (and cuttings)from wave-induced energies, residual tidal currents (which are typically very low in the Beaufort Sea) or from ice-scouring, are expected to be minimal in depths greater than about 20 m. In the high Arctic, the total ice cover in winter and the presence of a substantial number of ice floes in summer, will ensure that the bottom sediment material will only be influenced to any large degree in shallow areas (less than 20 m). Hence, except in areas of relatively strong currents, cuttings would remain in the discharge area for long periods.

The two geographical areas considered in this report are therefore based on the oceanographic and ice forces that control the movement of cuttings:

- shallow Beaufort Sea less than 20-m depth; and
- Beaufort Sea greater than 20-m depth and high Arctic islands (low-current areas).

C) Rating criteria. The ratings criteria used in Tables 6.2 to 6.7 to assess the environmental impacts from discharged cuttings are presented below. However, one of the difficulties in establishing these criteria is that the impact is not only a function of the amount of OBM adhering to the cuttings, but is also, and perhaps to a greater degree, a function of the volume of the cuttings discharged, which, in turn, is related to the size, depth, and number of wells drilled.

In comparing the different treatment options, only the oil retention was considered, i.e., it was assumed that the area covered by the cuttings would be similar for all systems. The ratings also refer to the area immediately adjacent to the well-head, the zone that will show the greatest impact. It is important to recognize, however, that as one moves away from the well, the degree of impact diminishes and that for any one well, all four levels of impact that are described, and used as ratings criteria, will be present.

The criteria are based, in part, on the information presented in Section 3, and in particular, from data gathered in the North Sea. In those studies, four zones of impact were described. These zones, and the approximate distance from the well site which they occur, are summarized below:

0-500 m : impoverished and highly modified benthic community; hydrocarbon levels 1000-plus times background.

200-2000 m : transition zone, with benthic diversity increasing; hydrocarbon levels 10-700 times background.

800-4000 m : no biological effects detected; hydrocarbon levels 1-10 times background.

>4000 : background levels.

The ratings (1-4) used in Tables 6.2 to 6.7, were based on the following definitions:

Rating Scale	Criteria
1	**Negligible Impact** - no noticeable change in biological community of elevated hydrocarbon concentrations in sediments; cuttings rapidly dissipated; no conflicts with other resources/resource users.
2	**Minor Impact** - no noticeable biological change; sedimentary hydrocarbon concentrations 1-10 times background; cuttings persistent only for duration of well; little likelihood of resources-use conflict.
3	**Moderate Impact** - noticeable change in biological community as a result either of direct toxicity or of organic enrichment; sedimentary hydrocarbon levels 10-1000 times background; cuttings persistent for one season only; presence of cuttings may conflict with resource use.

Table 6.2 Environmental Considerations

REGION OF ACTIVITY: Shallow Water-Winter DISPOSAL OPTION: Marine

BASE OIL USED: Diesel

ISSUES TREATMENT SYSTEMS	Oil Retention (%) a.	Burial of Benthos	Toxicity ($96hrLC_{50}$)	Community Changes	Tainting	Anoxic/H_2C Conditions	Impact on Resource Use/Users	Formation of Bottom Pavement
A. NORMAL SOLIDS CONTROL	15-25	4	4	4	4	4	2	4
B. SPRAY WASH								
1. N.L. Baroid, Neat	5-12	4	4	4	4	4	2	4
2. N.L. Modified Neat	8*	4	3-4	3-4	4	4	2	4
C. IMMERSION WASH								
3. Baroid Cuttings Processor	7-12	4	4	4	4	4	2	4
4. Dress./Magco. M.P.A.	15-20*	4	4	4	4	4	2	4
5. Drex. Cuttings Wash	6-28	4	4	4	4	4	2	4
6. Baroid CW4	b	4	b	b	b	b	2	4
7. Broad. Base oil Centrif. Wash	<10*	4	3-4	3-4	3-4	3-4	2	4
8. Dress. Wash Drum/Centrif.	1-20*	4	3-4	3-4	3-4	3-4	2	4
9. Drex. Wash Drum/Centrifuge	5*	4	3-4	3-4	3-4	3-4	2	4
10. Drex. U.K. Two-Stage Wash	<5	4	3	3	3	3	2	4
11. Drex. U.K. Three-Stage Wash	<5	4	3	3	3	3	2	4
12. Broad. Aqueous Centrif. Wash	3-9*	4	4	4	4	4	2	4
13. Sweco/Fis Trichloroethane	<1-3	3	2-3	2-3	2-3	2-3	2	3-4
14. CFS Supercritical Fluid	<1	3	2	2	2	2	2	3
D. THERMAL SYSTEMS								
D1. Distillation								
15. Hughes/Crew System	<1	3	2	2	2	2	2	3
16. Dress. Vibrating Drier	<1	3	2	2	2	2	2	3
17. Oil-Tools Disposal	<1*	3	2	2	2	2	2	3
18. Star Volitilizer	<1	3	2	2	2	2	2	3
D2. Combustion								
19 Hamjern Fluidized Bed	<1	3	2	2	2	2	2	3
20. Prochem. Fluidized Bed	<1	3	2	2	2	2	2	3
21. Incinerators	<1	3	2	2	2	2	2	3
E. ONSHORE STABILIZATION								
22. Leco/Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
23. Standard Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
24. Solidifiers	--	NA	NA	NA	NA	NA	NA	NA

a - g oil/100 g oil and water wet effluent, unless indicated (*)
* - g oil/100 g dry cuttings
b - no data available; effects unknown
NA - not applicable

Table 6.3 Environmental Considerations

REGION OF ACTIVITY: Shallow Water-Summer DISPOSAL OPTION: Marine

BASE OIL USED: Diesel

ISSUES TREATMENT SYSTEMS	Oil Retention (%) a.	Burial of Benthos	Toxicity (96hrLC$_{50}$)	Community Changes	Tainting	Anoxic/H$_2$S Conditions	Impact on Resource Use/Users	Formation of Bottom Pavement
A. NORMAL SOLIDS CONTROL	15-25	3-4	3-4	3-4	3-4	3-4	3-4	3-4
B. SPRAY WASH								
1. N.L. Baroid, Neat	5-12	3-4	3-4	3-4	3-4	3-4	3-4	3-4
2. N.L. Modified Neat	8*	3-4	3-4	3-4	3-4	3-4	3-4	3-4
C. IMMERSION WASH								
3. Baroid Cuttings Processor	7-12	3-4	3-4	3-4	3-4	3-4	3-4	3-4
4. Dress./Magco. M.P.A.	15-20*	3-4	3-4	3-4	3-4	3-4	3-4	3-4
5. Drex. Cuttings Wash	6-28	3-4	3-4	3-4	3-4	3-4	3-4	3-4
6. Baroid CW4	b	3-4	b	b	b	b	3-4	3-4
7. Broad. Base Oil Centrif. Wash	<10*	3-4	3-4	3-4	3-4	3-4	3-4	3-4
8. Dress. Wash Drum/Centrif.	1-20*	3-4	3-4	3-4	3-4	3-4	3-4	3-4
9. Drex. Wash Drum/Centrifuge	5*	3-4	3-4	3-4	3-4	3-4	3-4	3-4
10. Drex. U.K. Two-Stage Wash	<5	3-4	3-4	2-3	2-3	2-3	3-4	3-4
11. Drex. U.K. Three-Stage Wash	<5	3-4	3-4	2-3	2-3	2-3	3-4	3-4
12. Broad. Aqueous Centrif. Wash	3-9*	3-4	3-4	3-4	3-4	3-4	3-4	3-4
13. Sweco/Fis Trichloroethane	<1-3	2-3	3	2-3	2-3	2-3	2-3	2-3
14. CFS Supercritical Fluid	<1	2-3	2	2	2	2	2-3	2-3
D. THERMAL SYSTEMS								
D1. <u>Distillation</u>								
15. Hughes/Crew System	<1	2-3	2	2	2	2	2-3	2-3
16. Dress. Vibrating Drier	<1	2-3	2	2	2	2	2-3	2-3
17. Oil-Tools Disposal	<1*	2-3	2	2	2	2	2-3	2-3
18. Star Volitilizer	<1	2-3	2	2	2	2	2-3	2-3
D2. <u>Combustion</u>								
19. Hamjern Fluidized Bed	<1	2-3	2	2	2	2	2-3	2-3
20. Prochem. Fluidized Bed	<1	2-3	2	2	2	2	2-3	2-3
21. Incinerators	<2	2-3	2	2	2	2	2-3	2-3
E. ONSHORE STABILIZATION								
22. Leco/Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
23. Standard Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
24. Solidifiers	--	NA	NA	NA	NA	NA	NA	NA

a - g oil/100 g oil and water wet effluent, unless indicated (*)
* - g oil/100 g dry cuttings
b - no data available; effects unknown
NA - not applicable

Table 6.4 Environmental Considerations

REGION OF ACTIVITY: Shallow Water-Winter DISPOSAL OPTION: Marine

BASE OIL USED: Low-Toxicity

ISSUES TREATMENT SYSTEMS	Oil Retention (%) a.	Burial of Benthos	Toxicity ($96hrLC_{50}$)	Community Changes	Tainting	Anoxic/H_2S Conditions	Impact on Resource Use/Users	Formation of Bottom Pavement
A. NORMAL SOLIDS CONTROL	15-25	4	2	4	3-4	4	2	4
B. SPRAY WASH								
1. N.L. Baroid, Neat	5-12	4	2	4	3-4	4	2	4
2. N.L. Modified Neat	8*	4	2	3-4	3-4	4	2	4
C. IMMERSION WASH								
3. Baroid Cuttings Processor	7-12	4	2	4	3-4	4	2	4
4. Dress./Magco. M.P.A.	15-20*	4	2	4	3-4	4	2	4
5. Drex. Cuttings Wash	6-28	4	2	4	3-4	4	2	4
6. Baroid CW4	b	4	b	b	b	b	2	4
7. Broad. Base Oil Centrif. Wash	<10*	4	2	3-4	2-3	3-4	2	4
8. Dress. Wash/Drum Centrif.	1-20*	4	1-2	3-4	2-3	3-4	2	4
9. Drex. Wash Drum/Centrifuge	5*	4	2	3-4	2-3	3-4	2	4
10. Drex. U.K. Two-Stage Wash	<5	4	2	3	2-3	3	2	4
11. Drex. U.K. Three-Stage Wash	<5	4	2	3	2-3	3	2	4
12. Broad. Aqueous Centrif. Wash	3-9*	4	2	4	3-4	4	2	4
13. Sweco/Fis Trichloroethane	<1-3	3	1-2	2-3	1-2	2-3	2	4
14. CFS Supercritical Fluid	<1	3	1	2	1-2	2	2	3
D. THERMAL SYSTEMS								
D1. Distillation								
15. Hughes/Crew System	<1	3	1	2	1-2	3	2	3
16. Dress. Vibrating Drier	<1	3	1	2	1-2	3	2	3
17. Oil-Tools Disposal	<1*	3	1	2	1-2	3	2	3
18. Star Volitilizer	<1	3	1	2	1-2	3	2	3
D2. Combustion								
19. Hamjern Fluidized Bed	<1	3	1	2	1-2	2-3	2	3
20. Prochem. Fluidized Bed	<1	3	1	2	1-2	2-3	2	3
21. Incinerators	<1	3	1	2	1-2	3	2	3
E. ONSHORE STABILIZATION								
22. Leco/Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
23. Standard Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
24. Solidifiers	--	NA	NA	NA	NA	NA	NA	NA

a - g oil/100 g oil and water wet effluent, unless indicated (*)
* - g oil/100 g dry cuttings
b - no data available; effects unknown
NA - not applicable

Table 6.5 Environmental Considerations

REGION OF ACTIVITY: Shallow Water-Summer **DISPOSAL OPTION:** Marine

BASE OIL USED: Low-Toxicity

ISSUES TREATMENT SYSTEMS	Oil Retention (%) a.	Burial of Benthos	Toxicity ($96hrLC_{50}$)	Community Changes	Tainting	Anoxic/H_2S Conditions	Impact on Resource Use/Users	Formation of Bottom Pavement
A. NORMAL SOLIDS CONTROL	15-25	3-4	2	3-4	2-3	3-4	3-4	3-4
B. SPRAY WASH								
1. N.L. Baroid, Neat	5-12	3-4	2	3-4	2-3	3-4	3-4	3-4
2. N.L. Modified Neat	8*	3-4	2	3-4	2-3	3-4	3-4	3-4
C. IMMERSION WASH								
3. Baroid Cuttings Processor	7-12	3-4	2	3-4	2-3	3-4	3-4	3-4
4. Dress./Magco. M.P.A.	15-20*	3-4	2	3-4	2-3	3-4	3-4	3-4
5. Drex. Cuttings Wash	6-28	3-4	2	3-4	2-3	3-4	3-4	3-4
6. Baroid CW4	b	3-4	b	b	b	b	3-4	3-4
7. Broad. Base Oil Centrif. Wash	<10*	3-4	2	3-4	2-3	3-4	3-4	3-4
8. Dress. Wash Drum/Centrif.	1-20*	3-4	2	3-4	2-3	3-4	3-4	3-4
9. Drex. Wash Drum/Centrifuge	5*	3-4	2	3-4	2-3	3-4	3-4	3-4
10. Drex. U.K. Two-Stage Wash	<5	3-4	2	2-3	1-2	2-3	3-4	3-4
11. Drex. U.K. Three-Stage Wash	<5	3-4	2	2-3	1-2	2-3	3-4	3-4
12. Broad. Aqueous Centrif. Wash	3-9*	3-4	2	3-4	2-3	3-4	3-4	3-4
13. Sweco/Fis Trichloroethane	<1-3	2-3	1-2	2-3	2	2-3	2-3	2-3
14. CFS Supercritical Fluid	<1	2-3	1	2	1	2	2-3	2-3
D. THERMAL SYSTEMS								
D1. <u>Distillation</u>								
15. Hughes/Crew System	<1	2-3	1	2	1	2	2-3	2-3
16. Dress. Vibrating Drier	<1	2-3	1	2	1	2	2-3	2-3
17. Oil-Tools Disposal	<1*	2-3	1	2	1	2	2-3	2-3
18. Star Volitilizer	<1	2-3	1	2	1	2	2-3	2-3
D2. <u>Combustion</u>								
19. Hamjern Fluidized Bed	<1	2-3	1	2	1	2	2-3	2-3
20. Prochem. Fluidized Bed	<1	2-3	1	2	1	2	2-3	2-3
21. Incinerators	<1	2-3	1	2	1	2	2-3	2-3
E. <u>Onshore Stabilization</u>								
22. Leco/Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
23. Standard Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
24. Solidifiers	--	NA	NA	NA	NA	NA	NA	NA

a - g oil/100 g oil and water wet effluent, unless indicated (*)
* - g oil/100 g dry cuttings
b - no data available; effects unknown
NA - not applicable

Table 6.6 Environmental Considerations

High Arctic Region (low current areas)
REGION OF ACTIVITY: Beaufort Sea (> 20 m) DISPOSAL OPTION: Marine

BASE OIL USED: Diesel

TREATMENT SYSTEMS / ISSUES	Oil Retention (%) a.	Burial of Benthos	Toxicity ($96hrLC_{50}$)	Community Changes	Tainting	Anoxic/H_2S Conditions	Impact on Resource Use/Users	Formation of Bottom Pavement
A. NORMAL SOLIDS CONTROL	15-25	4	4	4	4	4	1	4
B. SPRAY WASH								
1. N.L. Baroid, Neat	5-12	4	4	4	4	4	1	4
2. N.L. Modified Neat	8*	4	4	4	4	4	1	4
C. IMMERSION WASH								
3. Baroid Cuttings Processor	7-12	4	4	4	4	4	1	4
4. Dress./Magco. M.P.A.	15-20*	4	4	4	4	4	1	4
5. Drex. Cuttings Wash	6-28	4	4	4	4	4	1	4
6. Baroid CW4	b	4	b	b	b	b	1	4
7. Broad. Base Oil Centrif. Wash	<10*	4	3-4	3-4	3-4	3-4	1	4
8. Dress. Wash Drum/Centrif.	1-20*	4	4	4	4	3-4	1	4
9. Drex. Wash Drum/Centrifuge	5*	4	4	4	4	3-4	1	4
10. Drex. U.K. Two-Stage Wash	<5	4	3	3	3	3-4	1	4
11. Drex. U.K. Three-Stage Wash	<5	4	3	3	3	3-4	1	4
12. Broad. Aqueous Centrif. Wash	3-9*	4	4	4	4	4	1	4
13. Sweco/Fis Trichloroethane	<1-3	3	3	3	3	2-3	1	4
14. CFS Supercritical Fluid	<1	3	2	2	2	2	1	3
D. THERMAL SYSTEMS								
D1. <u>Distillation</u>								
15. Hughes/Crew System	<1	3	2	2	2	2	1	3
16. Dress. Vibrating Drier	<1	3	2	2	2	2	1	3
17. Oil-Tools Disposal	<1*	3	2	2	2	2	1	3
18. Star Volitilizer	<1	3	2	2	2	2	1	3
D2. <u>Combustion</u>								
19. Hamjern Fluidized Bed	<1	3	2	2	2	2	1	3
20. Prochem. Fluidized Bed	<1	3	2	2	2	2	1	3
21. Incinerators	<1	3	2	2	2	2	1	3
E. ONSHORE STABILIZATION								
22. Leco/Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
23. Standard Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
24. Solidifiers	--	NA	NA	NA	NA	NA	NA	NA

a - g oil/100 g oil and water wet effluent, unless indicated (*)
* - g oil/100 g dry cuttings
b - no data available; effects unknown
NA - not applicable

Table 6.7 Environmental Considerations

REGION OF ACTIVITY: High Arctic Region (low current areas) Beaufort Sea (> 20 m) DISPOSAL OPTION: Marine

BASE OIL USED: Low Toxicity

ISSUES TREATMENT SYSTEMS	Oil Retention (%) a.	Burial of Benthos	Toxicity (96hrLC_{50})	Community Changes	Tainting	Anoxic/H_2S Conditions	Impact on Resources Use/Users	Formation of Bottom Pavement
A. NORMAL SOLIDS CONTROL	15-25	4	2	4	2-3	4	1	4
B. SPRAY WASH								
1. N.L. Baroid, Neat	5-12	4	2	4	2-3	4	1	4
2. N.L. Modified Neat	8*	4	2	4	2	4	1	4
C. IMMERSION WASH								
3. Baroid Cuttings Processor	7-12	4	2	4	2-3	4	1	4
4. Dress./Magco. M.P.A.	15-20*	4	2	4	2-3	4	1	4
5. Drex. Cuttings Wash	6-28	4	2	4	2-3	4	1	4
6. Baroid CW4	b	4	b	b	b	b	1	4
7. Broad. Base Oil Centrif. Wash	<10*	4	2	3-4	2	3-4	1	4
8. Dress. Wash Drum/Centrif.	1-20*	4	1-2	4	1-2	3-4	1	4
9. Drex. Wash Drum/Centrifuge	5*	4	2	4	2	3-4	1	4
10. Drex. U.K. Two-Stage Wash	<5	4	1	3	1-2	3-4	1	4
11. Drex. U.K. Three-Stage Wash	<5	4	1	3	1-2	3-4	1	4
12. Broad. Aqueous Centrif. Wash	3-9*	4	2	4	2	4	1	4
13. Sweco/Fis Trichloroethane	<1-3	3	1	3	1	2-3	1	4
14. CFS Supercritical Fluid	<1	3	1	2	1	2	1	3
D. THERMAL SYSTEMS								
D1. Distillation								
15. Hughes/Crew System	<1	3	1	2	1	2	1	3
16. Dress. Vibrating Drier	<1	3	1	2	1	2	1	3
17. Oil-Tools Disposal	<1*	3	1	2	1	2	1	3
18. Star Volitilizer	<1	3	1	2	1	2	1	3
D2. Combustion								
19. Hamjern Fluidized Bed	<1	3	1	2	1	2	1	3
20. Prochem. Fluidized Bed	<1	3	1	2	1	2	1	3
21. Incinerators	<1	3	1	2	1	2	1	3
E. ONSHORE STABILIZATION								
22. Leco/Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
23. Standard Quicklime Stabilization	--	NA	NA	NA	NA	NA	NA	NA
24. Solidifiers	--	NA	NA	NA	NA	NA	NA	NA

a - g oil/100 g oil and water wet effluent, unless indicated (*)
* - g oil/100 g dry cuttings
b - no data available; effects unknown
NA - not applicable

4 **Major Impact** - Impoverished and highly modified benthic community; hydrocarbon levels high, greater than 1000 times background; anaerobic sediments; cuttings persistent for more than one year; acutely toxic (e.g., within a few days); presence of cuttings piles likely to conflict with resource use such as fishing.

The criteria, or ratings, used to develop the environmental matrices were applied to the following issues or concerns:

- burial of benthic community
- toxicity (lethal 96-hr LC_{50} of the base oil only) to benthic, epibenthic, or pelagic organisms
- community alterations (e.g., enrichment)
- potential for tainting
- formation of anoxic/H_2S conditions
- impact on resource use/reserves
- formation of bottom pavement.

Matrices (see Tables 6.2 - 6.7) which summarize the ratings evaluating the impact of cuttings discharged to a marine environment were determined for the following combination of geographical areas and base oil types:

- shallow-water areas - winter period (ice cover) - DBM[1]
- shallow-water areas - winter period (ice cover) - LTM[2]
- shallow-water areas - summer period/ice break-up - DBM
- shallow-water areas - summer period/ice break-up - LTM
- Beaufort Sea (>20-m depth) and high Arctic Region (low-current areas) - DBM
- Beaufort Sea (>20-m depth) and high Arctic Region (low-current areas) - LTM

[1] DBM - Diesel oil-based mud
[2] LTM - Low-toxicity oil-based mud

Because the environmental factors must be determined on a site-specific basis, the matrices were based on an comparison of the different treatment systems, assuming a common environmental setting for each. The primary consideration when comparing the different systems was the amount of oil retained on the cuttings, which can vary between less than 1% to over 20%. A secondary consideration was the nature or consistency of the waste material,, which can range between a viscous, oily semi-solid (wash systems) to a fine, dry powder (combustion systems).

A number of other assumptions were made when considering the effects of cuttings in different geographical regions during different seasons, including:

a) It was assumed that the mixing of cuttings with, or burial by, natural sediments, and spreading of the cuttings pile by oceanographic processes, would reduce the overall impact by allowing a greater opportunity for biodegradation and by lowering of the concentration of oil present in the sediments. This assumption is based on the fact that burial of sediments by cuttings and organic enrichment were the two major impacts that were identified in the review of the literature.

b) It was also assumed that the mixing process would be much more likely in water depths of less than 20 m, when there was no ice cover, compared to (i) areas in water depths of greater than 20 m; or, (ii) in any water depth during the period of ice cover. The 20-m contour was selected because, under most oceanographic conditions, little sediment movement from waves was expected (see Section 2.2.1).

c) Toxicity and potential for tainting were assumed to be greater for cuttings from DBM compared to cuttings contaminated with LTM. It was also assumed that the potential for tainting would be higher under conditions where the cuttings pile would be more compact (e.g., during ice cover or in waters greater than 20 m in depth).

d) It was assumed that, in general, the nearshore Beaufort Sea was more important as a resource to user-groups compared to the deeper water regions of the Beaufort Sea and high Arctic waters.

6.3.2 Onshore Disposal Options

Land disposal options include burial in sumps or spreading over the land. The latter has been suggested for WBM and cuttings in the barren regions of the high Arctic. It is not likely to be considered for oil-based cuttings, however, because this material is less likely to freeze to the same degree and the oil presents a continuing contamination problem. This may be alleviated if the cuttings are combined with solidifiers (e.g. quicklime). The material is then likely to remain relatively inert, although no data from Arctic regions are available.

Sumps are more likely candidates for onshore disposal. If properly constructed and maintained, the environmental risk is considered slight. On the other hand, poorly constructed sumps, during summer and in an important waterfowl staging area, could result in considerable environmental impact. The lack of complete freezing of oil-based mud and cuttings, however, remains a problem with sump disposal.

The range of potential environmental impacts used to evaluate onshore disposal options are based on the information in presented in Tables 3.2 and 3.3. The ratings used in Table 6.8 are given below.

Rating Scale	Criteria
1	**Negligible** - properly constructed burial site with drainage lines upslope and no leakages; located away from vegetation zones and from any water body with sensitive biota.

2 **Minor** - properly constructed site; no leakage to local drainage; no minor damage to aquatic habitat or to surrounding vegetation.

3 **Moderate** - poorly constructed site; small leakages to non-sensitive aquatic habitats; local damage to surrounding vegetation.

4 **Major** - improperly constructed site; oil released to major staging area and/or sensitive aquatic habitat; permanent damage to, or alteration of, tundra.

Table 6.8 summarizes the environmental impacts for landfill wastes.

Table 6.8

Environmental impact ratings for onshore land-based disposal options

Waste material	Properly constructed Landfill sites	Poorly constructed Landfill sites
Untreated cuttings	1-2	3-4
Stabilized cuttings	1-2	1-2
Incineration ash	1-2	1-2

6.3.3 Incineration Options

Thermal systems for incinerations can be installed on board the drilling platform or placed at a convenient shore-based facility. The waste material from these systems is low in residual oil (see Section 6.3.1). At onshore drilling operations, or if the waste material is transported to shore from offshore sites, the material can be buried (see Section 6.3.2).

Thermal units, incinerators, or open-pit burning will generate air emissions in the form of particulates, partially combusted hydrocarbons, and NO_x and SO_x gases. The long-term effects of such emissions is considered to be negligible because the total quantity of waste is small. Local and short-term problems could occur if, for example, the units were located up-wind of a human settlement, in an area of poor circulation (e.g., temperature inversions in valleys), or near sensitive environmental habitats (e.g., nesting sites).

Precautions related to the timing of the use of the incinerator, to the location of burn sites, and to operator safety conditions, should mitigate against potential short-term environmental difficulties.

6.4 COST/BENEFIT CONSIDERATIONS

The cost of procuring (or leasing), maintaining, and operating a particular cuttings treatment system will be a factor (along with engineering/logistics and environmental considerations) in the final decision of which system to use.

A) **Capital costs.** The various treatment systems have been grouped into four ranges. Data on many systems area not available and these have been marked with an asterisk in the matrix (Table 6.9). Judgements were thus made on the basis of complexity, and comparisons with other systems, with respect to the level (1 to 4) in which they might fall.

Rating Scale	Range
1	$200,000 - $400,000
2	$400,000 - $600,000
3	$600,000 - $800,000
4	$800,000 +

B) **Operating costs.** These costs include dedicated personnel, process supplies, power, and financing. They are ranked on the basis of total costs per operating day. There was little information on operating costs for most of the systems and, therefore, the ranking is based on the experience and judgement of the authors. It was assumed that operating and maintenance, chemical, and personnel costs would be proportional to the ratings summarized in Table 6.1. For example, as the personnel or power requirement rating increases, so would the costs.

Rating Scale	Range (per operating day)
1	$ 500 - $1,500
2	$1,500 - $3,000
3	$3,000 - $4,500
4	$4,500 +

Both capital and on-structure operational costs were considered to be independent of the geographical location. However, the costs associated

Table 6.9 Financial Considerations

REGION OF ACTIVITY: All Regions

DISPOSAL OPTION: Marine and Land Base

BASE OIL USED: Not Applicable

ISSUES TREATMENT SYSTEMS	Capital Costs	Operating Costs	Vessel Support	Barge Costs	Dedicated Shorebase Facilities
A. ROUTINE SOLIDS CONTROL	1	1			
B. SPRAY WASH					
1. N.L. Baroid, Neat	1*	1			
2. N.L. Modified Neat	1*	1			
C. IMMERSION WASH					
3. Baroid Cuttings Processor	1*	1			
4. Dress.Magco. M.P.A.	4 a	2			
5. Drex. Cuttings Wash	1	2			
6. Baroid CW4	2*	2			
7. Broad. Base Oil Centrif. Wash	2*	3			
8. Dress. Wash Drum Centrifuge	2*	3			
9. Drex. Wash Drum Centrifuge	2*	3			
10. Drex. U.K. Two-Stage Wash	3	3			
11. Drex. U.K. Three-Stage Wash	4	3			
12. Broad. Aqueous Centrif. Wash	3 b	3			
13. Sweco/Fis Trichloroethane	2	2			
14. CFS Supercritical Fluid	4	3			
D. THERMAL SYSTEMS					
D1. Distillation					
15. Hughes/Crew System	4	3			
16. Dress. Vibrating Drier	2	3			
17. Oil-Tools Disposal	4	3			
18. Star Volitilizer	1*	3			
D2. Combustion					
19. Hamjern Fluidized Bed	4	4	4	2	2
20. Prochem. Fluidized Bed	4	4	4	2	2
21. Incinerators	1	2	4	2	2
E. ONSHORE STABILIZATION					
22. Leco/Quicklime Stabilization	1	3	4	2	2
23. Standard Quicklime Stabilization	1	3	4	2	2
24. Solidifiers			4	2	2

* - data not available; costs estimated on basis of complexity and comparison with other systems.
a - high costs due to prototype development
b - capacity dependent

with onshore disposal options, particularly from marine-based drilling platforms, will be affected by the area of operations. This cost will primarily be a function of dedicated vessel requirements for transport of cuttings to a shore-based facility.

6.4.1 Base Oils

Some manufacturers claim to be able to recycle the base oil to the drilling mud tanks, thus providing an economic incentive for these systems.

Little in the way of operational information is available to be able to judge accurately these claims. However, for wash and extraction systems, the spent wash fluid is likely to contain fines and ultra-fines which can be detrimental to the properties of the muds. In distillation systems, the oil may be subjected to thermal degradation. Further work is considered necessary to determine the effects of recycled oil and fines to the mud system (Davies 1984).

The present price structure for OBM has changed considerably. With early formulations,the difference in cost between diesel (considered the cheapest oil available) and low-toxicity base oils was quite large. However,in 1985, the price differential for a barrel of prepared drilling mud using the two types of base oil, was about 7%.

The assessment of the costs of the various treatment and disposal options was not done on the basis of the two types of base oils because this difference appears to be small relative to the overall costs.

6.4.2 Vessel Support

Cuttings treatment and disposal options involving shore-based facilities will very likely require a dedicated vessel. Because drilling vessel storage space is at a premium, little room would be available for storage of wastes generated from the drilling operation. This will generally preclude shipping of waste containers at regular intervals from the rig, thereby requiring a vessel or barge on standby for waste storage.

Because offshore drilling vessels have been designed to minimize the need for resupply during periods of ice cover, any operation dependent on surface vessel movements would partially negate the design purpose.

Operations in the remote, hostile environments of the Arctic increases the basic required capabilities for supply vessels in several areas. First, resupply routes are much longer than in other locations (e.g., Gulf of Mexico and the North Sea) and, therefore, the supply vessels require much greater capacity, speed, endurance, and seaworthiness. In addition, these vessels have to work in ice-infested waters requiring the use of ice strengthened hulls and increased ice-surveillance and ice-management capabilities.

The construction of an Arctic-class vessel is very costly. In the case of a Class III vessel, replacement costs today would be about $14-15 million. A Class IV vessel, such as is required before July or after October will cost in excess of $35 million.

These capital costs are increased by normal, daily operating costs, including fuel, crew, maintenance, and amortization of about $65,000 per day. By comparison, barge rates for storing and transfer of cuttings are about $1,200-1,500 per day. However, barges may not be appropriate in some circumstances (see Section 2.2.8).

7.0 CONCLUSIONS

The objective of this report was to provide information on the available methods for the treatment and disposal of cuttings contaminated with oil-based drilling muds.

The treatment systems were evaluated on the basis of engineering or operational criteria. Each system was also assessed with respect to the environmental concerns associated with various disposal options. Finally, financial information was presented to be able to assess the relative costs of pursuing a particular course of action.

The following factors need to be considered for each series of treatment and disposal options for oil-contaminated cuttings.

7.1 FACTORS INFLUENCING SELECTION OF TREATMENT AND DISPOSAL OPTIONS AT OFFSHORE WELLS

OPTION 1. ROUTINE SOLIDS CONTROL: MARINE DISCHARGE

- proven technology, reliable, considerable operator experience;
- lowest operating and capital costs of the three options;
- least complex system, requiring minimal dedicated operation or maintenance personnel;
- reduced environmental concern related to lower oil retention on cuttings;
- discharge of cuttings may result in an environmental impact depending on the base oil used or areas of drilling activity and environmental sensitivity; concern may be less with low-toxicity base oil, compared to diesel;
- environmental concern is related to the sensitivity of the area in which the cuttings are discharged, with coastal (shallow) Beaufort Sea region having the greatest sensitivity and the deep waters of the high Arctic the least sensitivity;
- if low-toxicity base oil is used, higher costs (7-8%) may be incurred, but there is potentially less environmental impact compared to diesel base oil; and
- biodegradation rates and long-term toxicity of discharged cuttings in Arctic waters are not known.

OPTION 2. ROUTINE SOLIDS CONTROL PLUS TREATMENT SYSTEM: MARINE DISCHARGE

- higher capital and operating costs, proportional to the complexity of the additional treatment system used (range: 200-400% increase over Option 1);
- increase in specialized operating and maintenance personnel and requirements for additional accommodation;
- increase in storage requirements for cuttings and process chemicals; and
- increase in space and power requirements.

OPTIONS 3. ROUTINE SOLIDS CONTROL: TRANSPORT TO SHORE FOR LAND DISPOSAL

- reduced on-board treatment requirements because only routine solids-control equipment used (see Option 1);
- much higher costs for support vessel or barges to transport cuttings to shore; specialized shorebase and off-loading requirements;
- on-board storage will be required; a barge stationed nearby to be used as storage not possible in all circumstances; barges will only carry cuttings already in containers;
- reduced marine environmental concern (discharges limited to accidental spills);
- environmental concerns related to poor land disposal practices; potential for impact not large if proper precautions taken (see Section 7.2); and
- minor terrestrial disturbance (e.g., 200-300 m^2 for single, exploratory well).

7.2 FACTORS INFLUENCING SELECTION OF TREATMENT AND DISPOSAL OPTIONS AT ONSHORE WELLS

OPTION 1. ROUTINE SOLIDS CONTROL: LANDFILL IN SUMPS

- on-site disposal; no transportation or storage costs; minimal logistical constraints;
- lowest operating and capital costs; only routine solids-control required;
- environmental concern reduced with proper preparation of landfill site; some locations may not be suitable (because of environmental concerns);
- nature of base oil not a factor with respect to environmental concerns; and,
- some environmental concern related to non-freezing of oil-based cuttings.

OPTION 2. ROUTINE SOLIDS-CONTROL AND INCINERATION: LANDFILL IN SUMPS

- additional storage and logistical requirements;
- increased capital and operating costs for equipment; and
- least concern with respect to environmental impact, although some short-term air emissions generated.

7.3 POINTS TO CONSIDER

The final decision as to which treatment and disposal option to undertake will require site-specific information and may not be the same course of action for all operations. However, the following points should be considered during the decision-making process.

1. Arctic field data are limited at present and, therefore, all environmental effects for marine disposal have been assessed using experience from temperate (primarily North Sea) waters.

2. Field data have not shown conclusively that diesel-based muds constitute a greater environmental hazard in marine waters compared to low-toxicity muds. The concern has been based primarily on laboratory 96-hour toxicity tests; however few data exist on long-term or sub-lethal effects.

3. The environmental effects of the discharge of cuttings to marine waters are mostly related to: (a) direct burial and suffocating, which is independent of the base oil used; and (b) organic enrichment, the presence of which appears to be the same for either diesel or low-toxicity oils.

4. For marine disposal, the primary concern is related to the amount of oil retained on the cuttings. Cost and complexity of a treatment system increases with its ability to remove oil. However, the more specialized systems, beyond routine solids control, have not been fully field-tested, and their ability to function correctly in the Arctic has yet to be determined.

5. The environmental effects of marine disposal will be a function of the amount of oil retained on the cuttings, the amount of cuttings discharged (single or multi-well discharge), the biological sensitivity of the area where they are discharged, and the degree of movement, mixing, or burial of cuttings with natural sediments. Also important to recovery are the physical and chemical characteristics of the cuttings, including low oxygen content, organic biodegradation rates, and the enrichment effect of higher organic loadings.

6. Incineration systems will favour diesel base oils because of lower price, greater availability, and minimum separate storage requirements. Because of the lower prices, losses and leakages are less of a financial concern, but good housekeeping practices must still be maintained.

7. Onshore disposal options, such as sumps, have the advantage of being cost-effective for onshore operations, if transportation costs area not large. Concerns over pooling and leaking of oil, can be addressed by using solidifiers, but at additional cost. Incineration and burial of ash has the lowest environmental risk of the onshore disposal options, but again at added cost. Land-spreading of oil-based mud cuttings, even if they are stabilized, is not likely to be considered as a workable disposal option.

8. For offshore operations, the treatment and disposal of cuttings onshore has a number of advantages. Less on-board equipment is required, there are reduced marine environmental concerns, and

onshore disposal options, with proper precautions, are likely to have minimal effect on the environment.

9. The logistics and cost of transport of cuttings from an offshore rig to a suitable onshore facility will involve the following:

   - dedicated barge or vessel for storage of cuttings; cuttings cannot be placed directly into vessels but first must be retained in movable containers (e.g., sea cans);

   - transfer of cuttings by barge can only be done during open-water season (likely after the winter drilling season);

   - rafting of barges near some offshore drilling platforms may not be possible, particularly over the winter period when ice may either endanger the barge or force the barge against the structure;

   - onshore disposal requires shorebased facilities for handling containers and transportation to facilities; and

   - landfill operations are subject to environmental regulation.

The final decision on which of the series of options to use must take into account engineering and logistical considerations, environmental considerations, and their relative cost and benefits. The advantages of the various options with respect to engineering and logistics are fairly clear. The decision is less clear with the environmental considerations, primarily because of the lack of information on the consequences of the different disposal options. Thus, the cost/benefit ratio of a particular course of action may not be readily apparent.

It is expected that many of the decisions on treatment and disposal will be site-specific. The environmental sensitivity of a particular site, for example, would clearly have to be considered. Also, options considered for production drilling may not necessarily be the same as for an exploratory well. However, it is hoped that the general considerations and information outlined in this report will provide the initial basis for developing waste-management guidelines for use in the context of Arctic hydrocarbon exploration and production.

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APPENDIX 1

Evaluation of Specialized Treatment Systems for Oil-Contaminated Cuttings

INTRODUCTION

The data in this appendix include a brief description of each system plus relevant references, which preceed each set of answers. Table A1 lists the considerations that were used in evaluating the different treatment systems. The information was compiled by S.R. H. Davies of the Institute of Ocean Engineering, Heriot-Watt University.

The following points should be noted when appraising the data that follow.

Costs

Most of the costing information supplied is valid for late 1984. Cost data obtained for earlier years are always qualified by a date. No attempt has been made to convert Deutschmark, Norwegian Kroner, Pounds Sterling or U.S. dollars to any 'standard' currency, as European currencies have been somewhat volatile over the last couple of years. All dollars are U.S. dollars.

System Efficiency

Unfortunately, a vast range of methods of analysis and methods of expressing the amounts of oil retained on discharged cuttings has been used. Simply expressing oil on cuttings as a % w/w retained on cuttings is not particularly meaningful as further clarification is required. Where possible, the following expressions are used:

a) g oil/100 g effluent or % wet weight = weight of oil associated with 100 grams of (oil + water + solids)

b) g oil/100 g of dry cuttings = weight of oil associated with 100 grams of dry (usually retorted) solids

The first expression gives an indication of the oil content of the material discharged overboard, but the result may be artificially low (due to absorption of water by hydrateable cuttings) if the cuttings have been subjected to an aqueous wash or sluice. This also holds true for results based on dried solids if the method of analysis employs solvent extraction rather than retort (in this case, the solids may not be totally water-free). The second expression, if based on retorted cuttings, is useful in eliminating the effect of water taken up by hydrateable cuttings and can be used to obtain a correction factor if expression of oil on water-washed cuttings is desired on a wet (effluent) basis. It should be noted that the expression 11% dry weight should be avoided as, although the classic definition would be:

$$\frac{\text{wt oil}}{\text{wt (oil + cuttings)}} \times 100$$

the industry has tended to adopt:

$$\frac{\text{wt oil}}{\text{wt cuttings}} \times 100$$

The expression wt % (or % w/w) should only be used if it is not known whether the figures are expressed as a wet or dry basis.

Operational Considerations - Cuttings Throughput

All capacities have been converted (where necessary) to a mass flow (tonnes/hour) of oily feed to the treatment system. It has been assumed that the cuttings have a formation bulk specific gravity (in-situ rock plus interstitial water) of 2.15 and that the feed is contaminated with 25 wt % oil on cuttings. Obviously the capacity of a thermal system (e.g., distillation and combustion) will vary with the oil and water content of the cuttings. In this case, a capacity is given for feed containing 25 wt %, 10 wt % water and 65 wt % rock (calculated by heat balance).

The answers to Questions 1a to e, 2a to d, 4b and c, 5 a to d in Table A1 are, unless stated, based on the opinions of the author.

Table A1

CONSIDERATIONS IN EVALUATING TREATMENT/DISPOSAL OPTIONS OF CONTAMINATED CUTTINGS FROM OIL-BASED MUD SYSTEMS

1. CAPITAL COSTS - Amount (nearest $000)

   Considerations

   a. Is the process dedicated to drilling on a production rig or exploration rig?

   b. Is the process dedicated to a rig working under certain environmental regulations?

   c. It the process moveable to other rig situations (flexibility of installation)?

   d. What is the period of use on site or in the situation?

   e. What is the operating life of the service.

2. MAINTENANCE COSTS - Amount/Month

   Considerations

   a. What is the frequency of maintenance/duration of downtime?

   b. What is the cost of parts?

   c. What is the handling ease of parts?

   d. What is its ability to operate at reduced capacity during system maintenance (e.g., can systems be maintained during trips and other periods when cuttings are not being produced)?

3. SYSTEM EFFICIENCY

   a. What is the oil removal effectiveness (re: environmental concerns)?

   b. What is the oil consumption vs. oil recovery (economics)?

4. OPERATIONAL CONSIDERATIONS

   a. Maximum throughput of the unit.

   b. Level of supervision required or degree of supervision?

   c. Operator skill/education requirements (i.e., the lowest level considered may include extra duties for rig hands with occasional tune-up visits from a technician)?

d. Extra crew size required (offshore accomodation is at a premium)?

e. Continuous vs. batch processing; what are the storage requirements (should include surge and supplies/consumables considerations)?

f. Energy consumption requirements (some situations, e.g., production platforms, may have surplus power, while the opposite would be in effect on most exploration rigs).

5. SAFETY CONCERNS

a. Potential damage to rigs?

b. Potential hazards for personnel?

c. Fire hazards?

d. Air pollution hazards?

6. SPACE AND STORAGE

a. Space: Equipment types, batch hoppers, crushing mills, centrifuges and incineration.

b. Storage: Batch vs. continuous processing. Cleaning fluid storage, surge tanks for continuity of operations.

c. Weight: Important consideration on floating rig.

APPENDIX 1: Operating, Engineering and Logistic Information for Individual Treatment Systems

SPRAY WASH

1. NL Baroid (UK) Ltd. Neat System
2. Modified 'NEAT' System used on Valhall
3. NL Baroid (UK) Ltd. Cuttings Processor

IMMERSION WASH

4. Dresser Magcobar/Mobil Oil Corp. MPA Systems
   - a) Beryl A. Platform
   - b) Statfjord A. Platform
   - c) Statfjord B. Platform
5. Drexel Equipment (UK) Ltd. Cuttings Wash System
6. NL Baroid CW4 Separate System
7. Thomas Broadbent and Sons Ltd. Base Oil Centrifuge Wash System
8. Dresser Swaco Wash Drum/Centrifuge System
9. Drexel Norway Wash Drum/Centrifuge System
10. Drexel Equipment (UK) Ltd. Multistage Wash System - Two Stage
11. Drexel Equipment (UK) Ltd. Multistage Wash System - Three Stage
12. Thomas Broadbent and Sons ltd. Aqueous Centrifuge Wash System
13. Sweco/FIS Trichloroethane Wash System
14. Critical Fluid Systems Inc. Supercritical Fluid Leaching Process

DISTILLATION SYSTEMS

15. Hughes Drilling Fluids CREW system
16. Dresser Swaco Vibrating Bed Cuttings Drier
17. Oiltools Cuttings Disposal System
18. Star Industries "Volitilizer" Incineration Process

COMBUSTION SYSTEMS

19. Hamjern A/S Fluidized Bed Combustion System
20. West's Prochem/Walsh Prochem Fluotherm Fluidized Bed Combustor
21. Incinerators

STABILIZATION SYSTEMS

22. Buchen and Leo GMBH LECO Quicklime Stabilization System
23. Standard Quicklime Stabilization Systems
24. Solidifers

MISCELLANEOUS, UNTESTED SYSTEMS

25. Mobil Oil Corporation Briquetting System
26. Thule Ultrasonics Assisted Wash System
27. Chromalloy Delta Mud Sluiceway System
28. Mudtools/FIS Trichloroethane Centrifuge Wash System

NL Baroid (UK) Ltd. NEAT System

Type: Spray/wash with aqueous/detergent or diesel/surfactant

References 1, 2, 3, 4.

The NEAT (No Effluent Accompanies Tailings) system processes cuttings by washing and de-liquefying the cuttings on a double-deck shaker screen fitted with spray bars along part of the screen length. The cuttings then fall down a sluiceway/caisson for further oil recovery. Screen underflow is cycloned and/or centrifuged for fines removal and to prolong wash fluid life. Wash fluid used is normally aqueous detergent solution, although a diesel/surfactant fluid has also been tested. Spent aqueous wash fluid is discharged overboard whilst spent diesel-based wash fluid could, it is claimed, be recycled to the active mud system.

Answers to Questions.

1. CAPITAL COSTS

   Most of the units were rented to operators. Holder (1) states that for a tandem (e.g., twin shaker) NEAT system installed on the Montrose Platform, rental of the cuttings wash system was $4500/well in 1982 (e.g., $150/day for a 30-day well). Total cost (including cuttings wash system, wash solution and personnel) was $2500/day.

   a. Could be fitted on either.

   b. Was considered acceptable for drilling in Dutch Sector (2) as well as UK Sector.

   c. Yes (fairly small and light).

   d. Used during drilling with diesel oil-based muds.

   e. Depends on how hard the system is driven and how well it is maintained. Individual items (e.g., pumps, cones, screen meshes) can be changed when necessary.

2. MAINTENANCE COSTS

   Not known.

   a. Depends on severity of use - Ref. 5 gives 5-10% downtime, mainly for screen changes.

   b. Not known.

   c. If unit employs tandem shakers, system could operate at 50% capacity during screen changes. System could operate whilst maintaining cyclones/centrifuges. System could not operate whilst maintaining circulation pump (unless 2 fitted).

3. SYSTEM EFFICIENCY

   a. 5-7 wt % (retorting) (reduced from 12-16 wt %) with aqueous wash fluid. 11-12 wt % (solvent extraction and infra red analysis) with diesel wash fluid (Ref. 5). These tests were short-term and not necessarily representative of the well-averaged results. Remember spent aqueous wash fluid was discharged overboard.

   b. No oil recovered from aqueous wash system. Insufficient data to predict recovery for diesel wash system.

4. OPERATIONAL CONSIDERATIONS

   a. 2.7 tonnes per hour for a single shaker unit, 5.4 tonnes per hour for a tandem shaker unit.

   b. System would need checking at intervals similar to solids control equipment.

   c. Solids control engineer could oversee.

   d. Holder (1) states 2 engineers are required.

   e. Continuous process. Surge facilities not used. Storage required for chemicals (unpublished data indicate 3 bbl/hour diesel wash fluid make-up was required; amount for aqueous wash is not known but is likely to be higher).

   f. Estimated to be 10 kW for single shaker unit, 16 kW for tandem shaker unit.

5. SAFETY CONCERNS

   a. Unlikely.

   b. If diesel wash fluid, same hazards (dermatitis, fumes) as solids control equipment. If aqueous wash fluids, low hazard.

   c. As above.

   d. None (other than fumes).

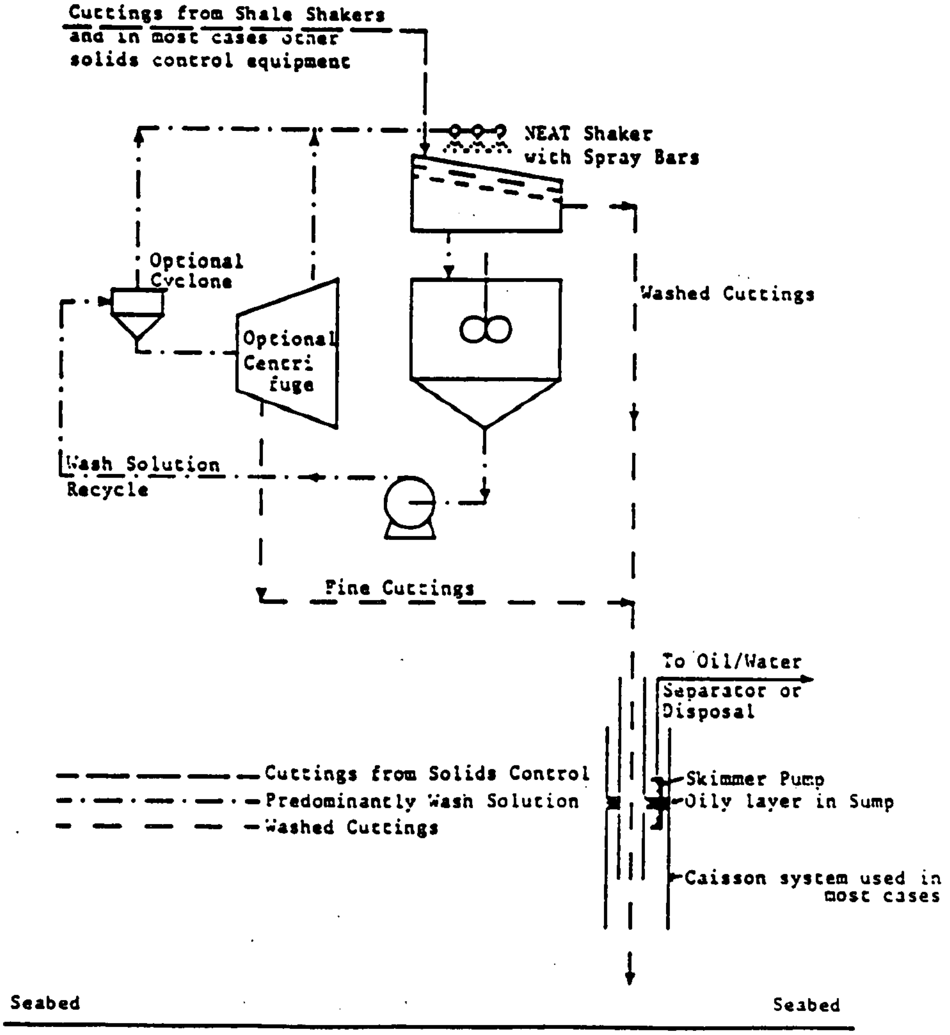
6. SPACE AND STORAGE

   a. Unconfirmed data suggest that skid mounted package occupies 2 x 3.4 x 2 m (L x W x H).

   b. Wash fluid held in anything from one 2 bbl to two 50 bbl circulating tanks per system.

   c. Wet weight will depend on wash fluid tank size. One unconfirmed figure gives 11 tonnes (wet) for a tandem shaker unit.

TYPICAL NL BAROID NEAT SYSTEM



Modified 'NEAT' System Used on Valhall

Type: Spray wash, aqueous solution

Reference 15.

In this system, disposal of spent aqueous wash fluid is completed by utilizing a burner to 'combust' the spent wash fluid. See Figure 1 for system layout.

Answers to Questions.

1. CAPITAL COSTS

   Not known.

   a. Either.

   b. Used in Norwegian Sector of North Sea.

   c. Yes.

   d. Used when drilling with diesel or 'low toxicity' oil-based muds (the latter has replaced the former).

   e. Not known - individual items (screens, pumps, etc.) can be replaced when necessary.

2. MAINTENANCE COSTS

   Not known.

   a. Not known - wash fluid requires changing every 45-90 minutes, depending on drilling conditions.

   b. Not known.

   c. Items such as pumps and screens are relatively easy to handle. The oil/water separator and tanks may be bulky.

   d. 4 screens are used hence can operate at reduced capacity, except during wash fluid changeout.

3. SYSTEM EFFICIENCY

   a. Typically 7.5 g oil/100 g dry (retorted) cuttings (well-average basis).

   b. No oil recovered - disposal burner is now fuelled by gas but if diesel were used, up to 3,000 bbl/well of diesel would be required to combust the spent aqueous wash fluid.

4. OPERATIONAL CONSIDERATIONS

a. 13.5 tonnes/hour oily cuttings.

b. System would need checking at intervals similar to solids control system.

c. Solids control engineer could oversee.

d. Not known - probably 1 per shift.

e. Continuous process. No surge facilities. Storage required for chemicals (it is estimated that up to 32 bbls/day concentrated CW4 surfactant is used).

f. Estimated around 35 kW.

5. SAFETY CONCERNS

a. Unlikely.

b. Low hazard - though properties of concentrated CW4 unknown.

c. Low hazard - though properties of concentrated CW4 unknown.

d. Typically 5000 m^3/well of spent aqueous wash fluid requires disposal by 'combustion'. There is a potential for incomplete combustion.

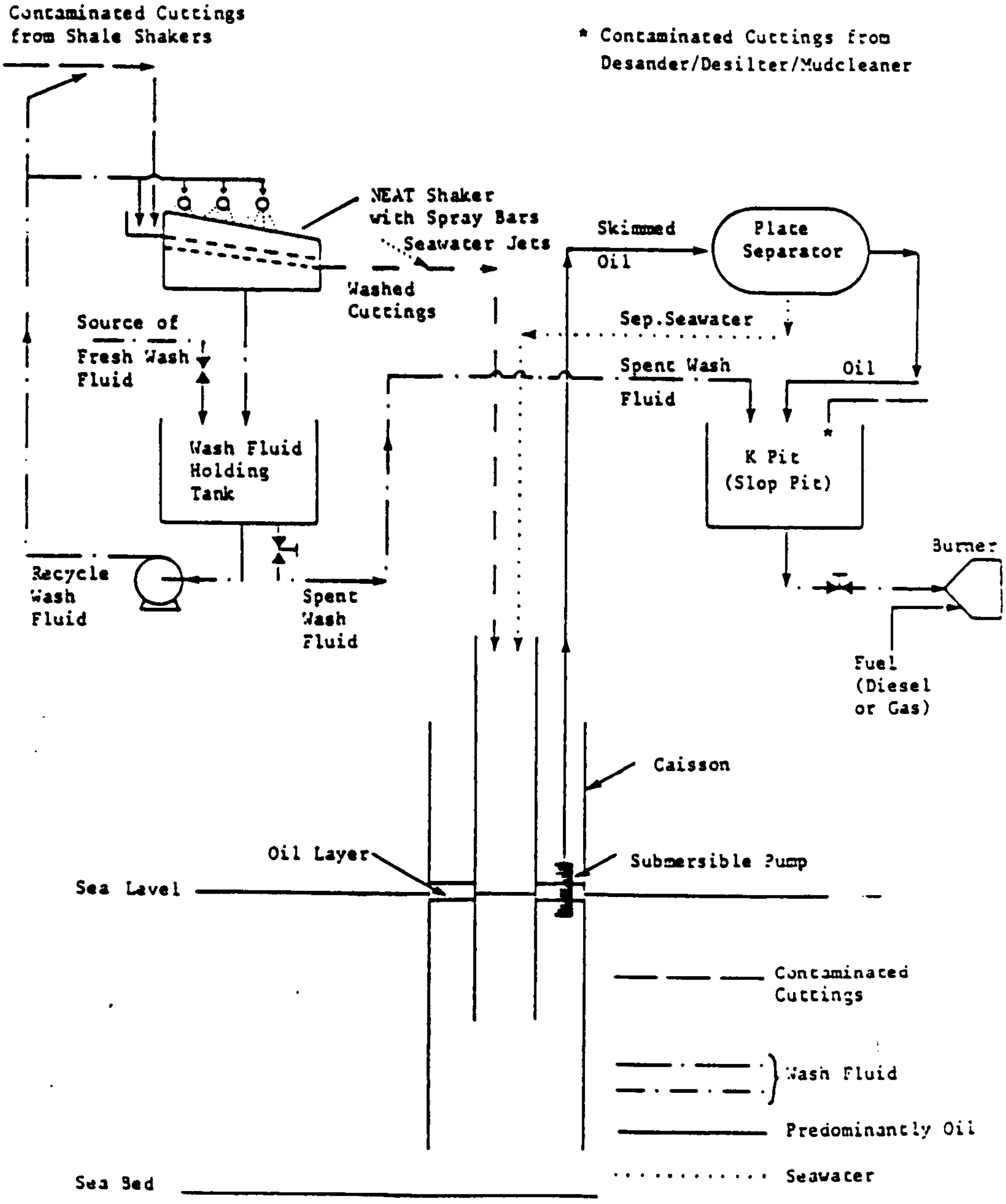
6. SPACE AND STORAGE

a. Space required for 4 'NEAT' shakers, 33 bbl wash fluid holding/ circulation tank, pumps and oil/water separator.

b. Storage space also required for concentrated CW4 surfactant storage.

c. Not known.

SIMPLIFIED DIAGRAM OF MODIFIED NEAT SYSTEM ON VALHALL



NL Baroid (UK) Ltd. Cuttings Processor

Type: Immersion wash, 1 stage: aqueous or diesel.

References 1, 3, 4, 5.

Cuttings drop into a 50 bbl agitated tank (containing aqueous or diesel wash solution) and the resulting slurry is pumped over 1 or 2 double-deck shakers. Oversize cuttings are discharged down a sluice, screen unders drop back into the tank. Spent aqueous wash fluid is discharged overboard whilst spent diesel could, it is claimed, be recycled to the active mud system.

Answers to Questions.

1. CAPITAL COSTS

   Most of the units were rented.

   a. Could be fitted on either.

   b. Was thought to have been developed in U.S. Used in UK Sector of the North Sea (at time of no regulations).

   c. Yes (fairly small and light).

   d. Used during drilling with diesel oil-based muds.

   e. Depends on how hard system is driven and how well it is maintained. Individual items (pumps, cones, screens) can be changed when necessary.

2. MAINTENANCE COSTS

   Not known.

   a. Depends on severity of use.

   b. Not known.

   c. Relatively easy (pumps, screens, tanks).

   d. Limited. If unit employs tandem shakers, system could operate at 50% capacity during screen changes.

3. SYSTEM EFFICIENCY

   a. 12% wet weight (solvent extraction and ultraviolet fluorimeter analysis) with aqueous wash fluid (Ref. 5). Other data suggest 7% wet weight (solvent extraction and ultraviolet fluorimeter analysis) (Ref. 6) and 7.5 to 8.2 g oil/100 g dry cuttings (retorting) (Ref. 7). No data are available for diesel wash fluid.

The above data are based on tests of short duration and are not necessarily representative of well-averaged results. Remember the spent aqueous wash fluid was discharged overboard.

b. No oil recovered from aqueous wash system. Insufficient data to predict recovery for diesel wash system.

4. OPERATIONAL CONSIDERATIONS

a. 8 tonnes/hour for a single shaker unit, 16 tonnes/hour for a tandem shaker unit.

b. System would need checking at intervals similar to solids control equipment.

c. Solids control engineer could oversee.

d. 1 per shift.

e. Continuous process. Surge facilities not used. Storage required for chemicals - no data are available for consumption rates.

f. 40 kW for single shaker unit, 16 kW for tandem shaker unit.

5. SAFETY CONCERNS

a. Unlikely.

b. If diesel wash fluid, same hazards (dermatitis, fumes) as solids control equipment, if aqueous wash fluid, low hazard.

c. As above.

d. None, other than fumes.

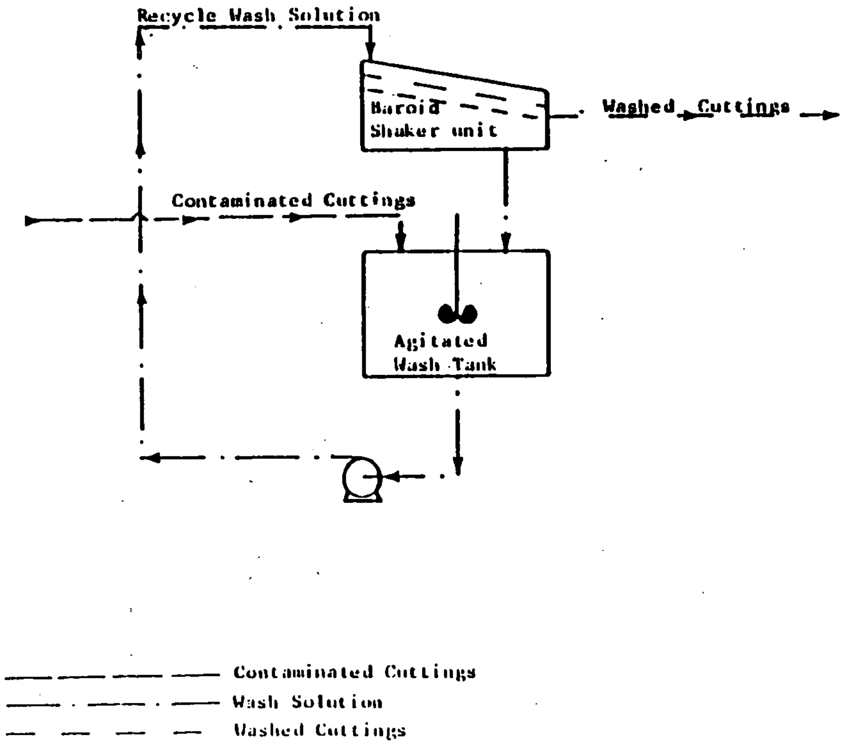
6. SPACE AND STORAGE

a. Skid mounted package occupies 3.5 x 2.3 x 2.0 m (L x W x H) for single shaker unit or 4.0 x 2.3 x 2.0 m for tandem shaker unit.

b. Wash fluid held in 50 bbl circulating tank.

c. 4/5 tonnes dry, 12/13 tonnes wet (for single/tandem shaker units).

NL BAROID CUTTINGS PROCESSOR



NL BAROID CUTTINGS PROCESSOR

Dresser Magcobar/Mobil Oil Corp. MPA Systems

Type: Immersion wash, 1 stage with diesel

References 8, 9, 10, 11, 12.

The MPA (Mud Processing Area) system is a combined mud solids control/ cuttings cleaning package that has been used by Mobil on the Beryl A and Statfjord A and B platforms. They are essentially similar. Coarse cuttings are washed in an agitated tank containing diesel then dried on shaker screens. Fine cuttings are washed in a similar tank then dried on fine screens and/or in cyclones and centrifuges. Wash fluid is re-cycled to the tanks, coarse solids are discharged down a sluice and fine solids are either discharged down the sluice or burned along with spent wash fluid.

Answers to Questions.

1. CAPITAL COSTS

   Beryl A - rented at $30,000/month. Bought when accrued rental equalled system value, namely $1,425,000 in early 1981.

   Statjford A - cost $2.5-3 million in 1980.

   Statjford B - although capital cost of equipment was only $1 million, package cost $10.3 million to install.

   a. These integrated systems were designed for platforms.

   b. Designed for operation in UK and Norwegian Sectors of North Sea.

   c. Large modularized system - would probably prove difficult to move.

   d. Used at all times during drilling (as was diesel oil-based mud).

   e. Not known. Individual items (pumps, cones, screens) can be changed as necessary.

2. MAINTENANCE COSTS

   Not known.

   a. Not known.

   b. Typically $6200/month.

   c. Relatively easy (cyclones, centrifuges, pumps, screens and smaller tanks), bulky (275 bbl holding tank for spent fluids and fines).

   d. Where there are 3 screens for treating coarse cuttings system can run at reduced capacity. On Statfjord A (having 1 screen) the system could not.

3. SYSTEM EFFICIENCY

a. Beryl A - Testing (of short duration) over the years 1977-1982 indicates a range of 6.6-14.1 % wet weight oil on cuttings (measured by ultraviolet fluorimeter analysis or retorting).

Statfjord A and Statfjord B - longer term test data suggest a range of 15-20 g oil/100 g dry (retorted) cuttings on a well-averaged basis.

b. No oil recovered.

4. OPERATIONAL CONSIDERATIONS

a. Beryl A: 6.6 tonnes/hour (of oily cuttings), Statfjord A and B: 13.3 tonnes/hour.

b. Constant supervision required.

c. Typically a project manager, drilling fluids engineer, mechanics and roustabouts are required to run the complete system.

d. 5-8 persons on board to run the complete system.

e. Continuous process. Surge facilities not used (wash tanks act as buffers). Diesel wash fluid stored in bulk (diesel also used as fuel). Consumption of diesel (as wash fluid and burn fluid) is variable but can range from 2000-3000 bbls/well.

f. Beryl A - 492 kW total.
Statfjord A - 520 kW total.
Statfjord B - 1000 kW total.
Remember that the above data include the solids control equipment.

5. SAFETY CONCERNS

a. Unlikely.

b. Fumes, dermatitis.

c. Diesel in open tanks presents a potential hazard.

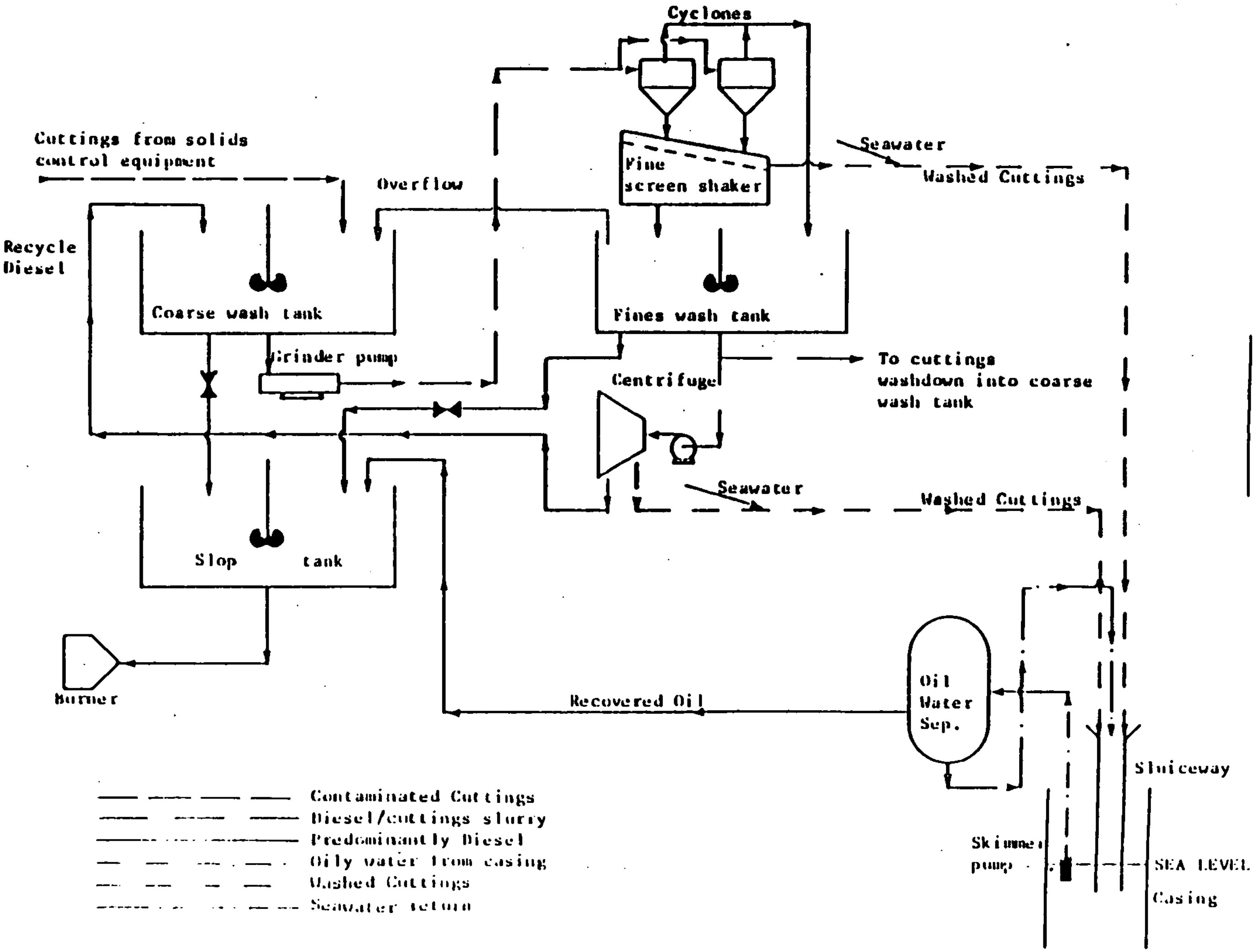
d. 2000 - 3000 bbl/well combusted.

6. SPACE AND STORAGE

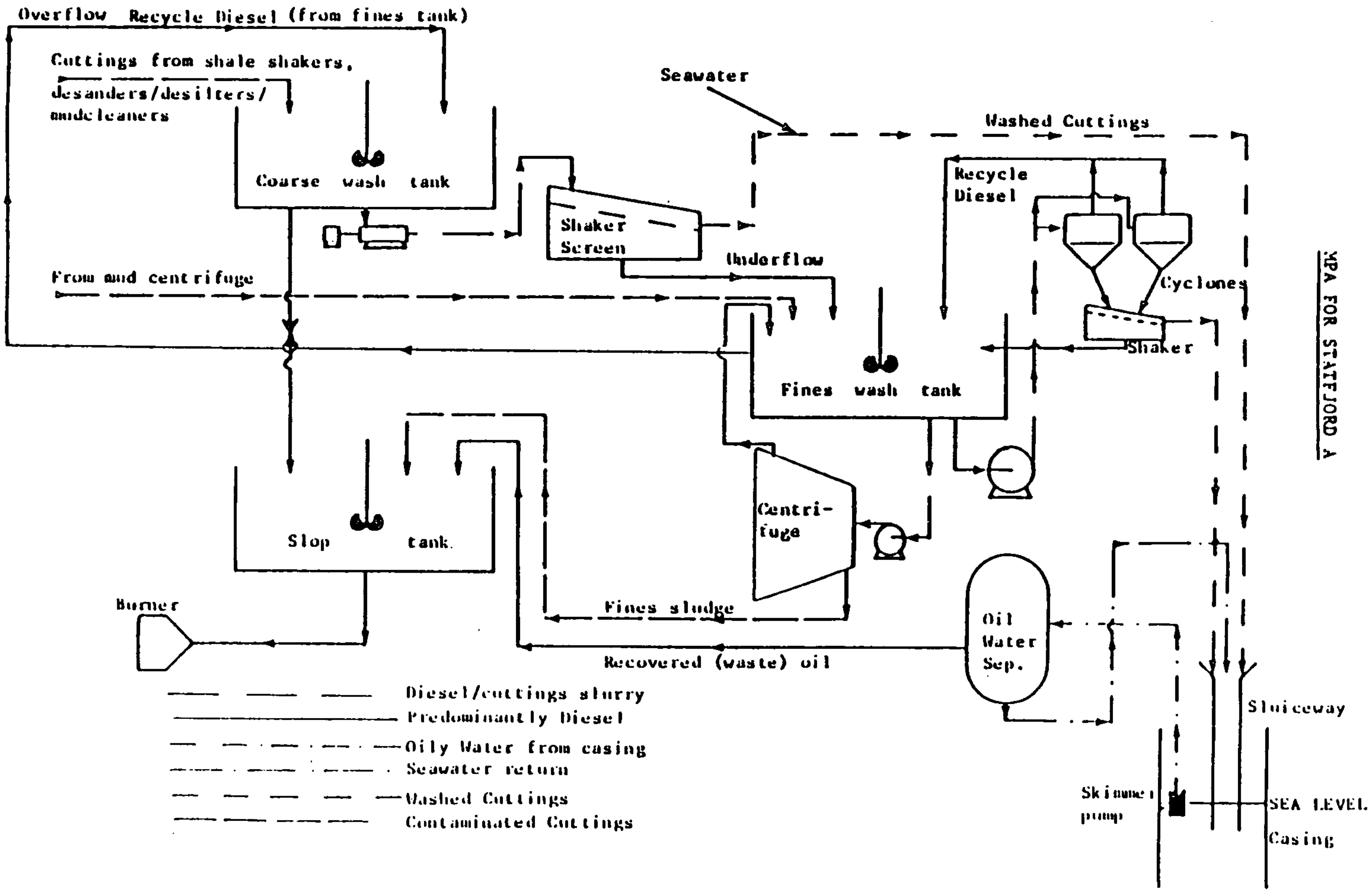
a. The equipment (including tanks) is housed in a module having 3 levels, of dimensions 19 x 6 x 7.5 m (L x W x H). (The system on Statfjord B occupies still more space).

b. Wash tanks (4 of) each hold 50 bbl of diesel, slop tank holds 275 bbl of spent wash fluid and fines.

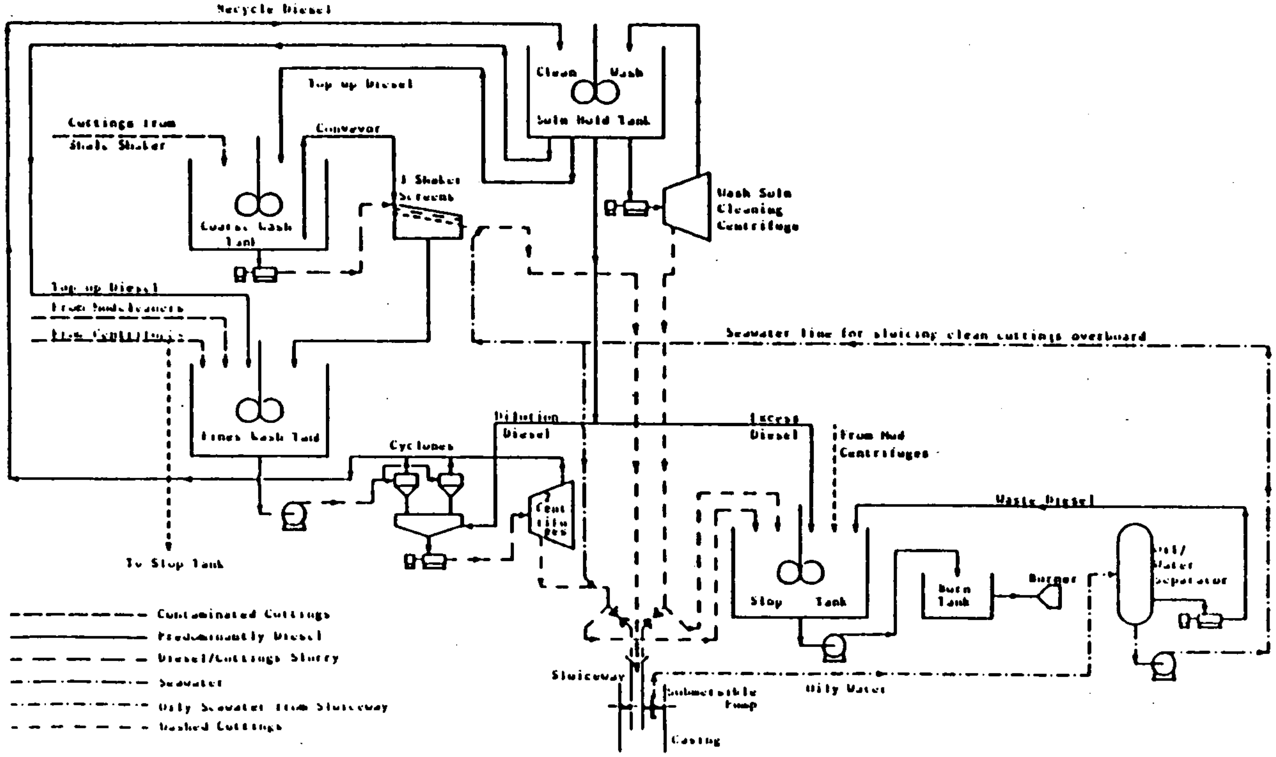
c. Beryl A - not known.
   Statfjord A - 460 tonnes dry.
   Statfjord B - 540 tonnes dry, 850 tonnes wet.
   Remember this includes the solids control system.



MPA FOR BERYL A



MPA FOR STATFJORD A



MPA FOR STATFJORD B

Drexel Equipment (UK) Ltd. Cuttings Wash System

Type: Immersion wash, 1 stage, with diesel.

References 5, 13.

Cuttings are washed in an agitated tank usually containing diesel. The resulting slurry is pumped over a shaker screen and through cyclones and (usually) a centrifuge. Solids from these units are discharged overboard, liquid (wash fluid) returns to the wash tank. The system is based on Brandt (USA) cleaning modules. A typical package is two modules (each containing tank, shaker, pumps and cyclones) feeding one centrifuge. Spent diesel wash fluid could, it is claimed, be recycled to the active mud system. Sweco developed a similar system (utilizing circular shaker units) that also used diesel wash fluid.

Answers to Questions.

1. CAPITAL COSTS

   Around $100,000 for typical package.

   a. Either.

   b. Used on platforms/rigs in UK Sector of North Sea.

   c. Yes (each module fairly small and light).

   d. Used during drilling with oil-based muds.

   e. Not known - individual items (screens, pumps, motors, etc. can be changed as necessary).

2. MAINTENANCE COSTS

   Not known.

   a. Depends on severity of use - screen life is typically 7-10 days (for Sweco system).

   b. Not known.

   c. Relatively easy (pumps, cyclones, centrifuge, tanks, screens).

   d. Typical package could operate at 50% capacity.

3. SYSTEM EFFICIENCY

   a. Various short-term tests have yielded oil on cuttings levels between 15 and 28 % wet wt (solvent extraction and ultraviolet fluorimeter analysis) (Ref. 14) or 6-8 wt % (solvent extraction and infra red spectroscopy analysis) (Ref. 5).

   b. Insufficient data available to predict oil recovery.

4. OPERATIONAL CONSIDERATIONS

a. 5.7 tonnes/hour oily cuttings for typical Drexel package, 40 tonnes/hour peak claimed for Sweco (with 4 screens).

b. System would need checking at intervals similar to solids control equipment.

c. Solids control engineer could oversee.

d. 1 per shift.

e. Continuous process. No surge tanks (wash fluid tanks act as buffer). Diesel wash fluid stored in bulk (also used as fuel etc.).

f. 50 kW for typical Drexel package, 75 kW for Sweco.

5. SAFETY CONCERNS

a. Unlikely.

b. Dermatitis, fumes.

c. Diesel in open tanks presents a potential hazard.

d. None (other than fumes).

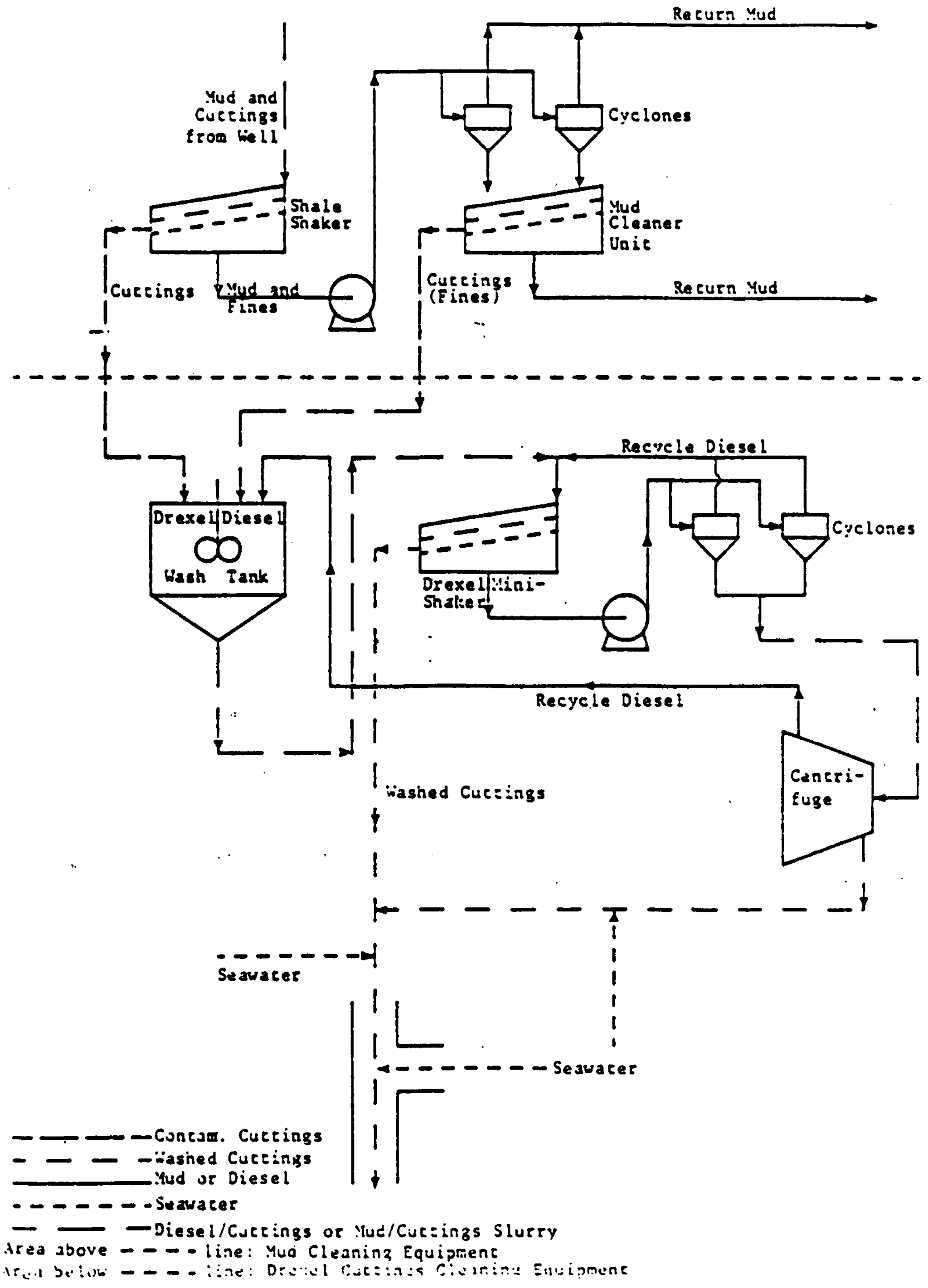
6. SPACE AND STORAGE

a. 4.4 x 3.2 m floor space for typical Drexel package, Sweco similar.

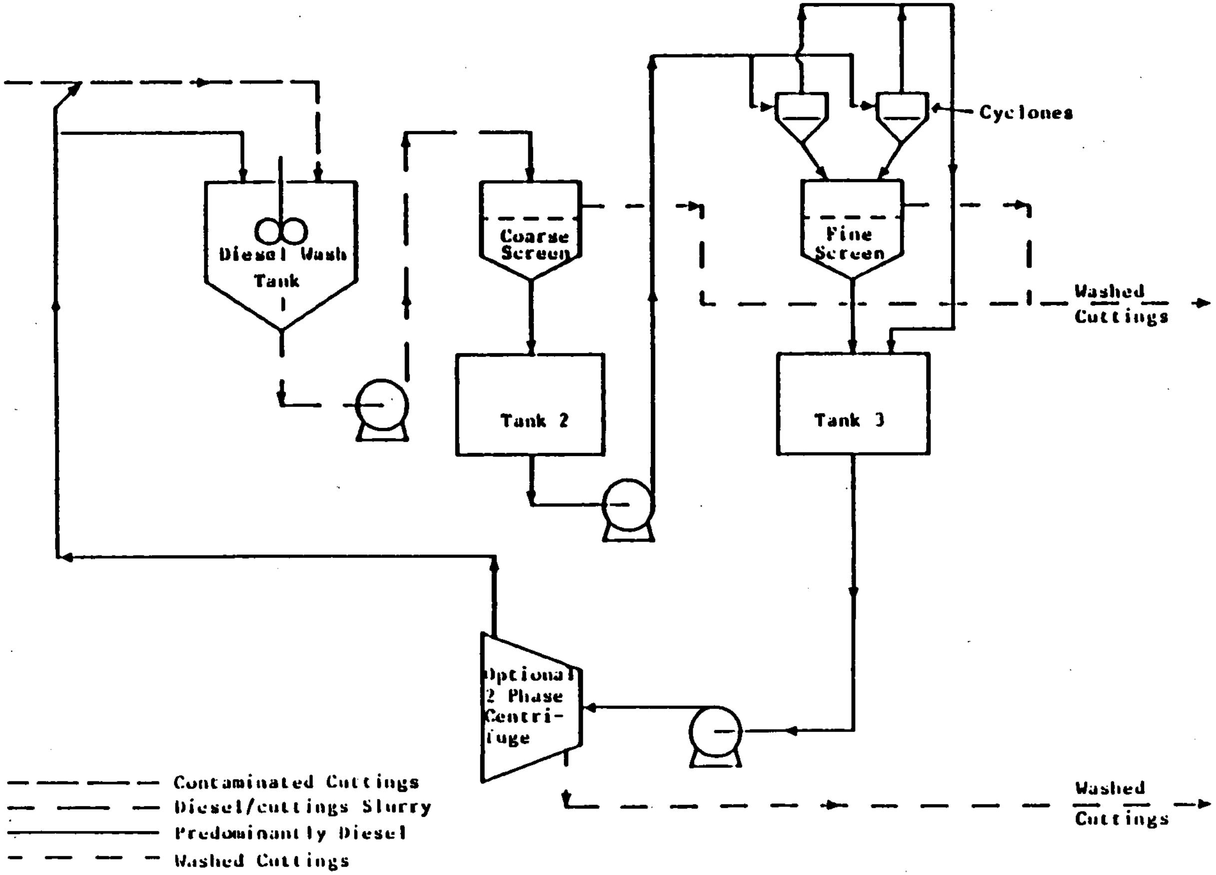
b. Each Drexel wash tank holds 11 bbl of diesel, the Sweco system requires 50 bbl.

c. Around 10 tonnes wet for a typical Drexel package, 30 tonnes wet for typical Sweco package.

DREXEL SINGLE STAGE CUTTINGS WASH SYSTEM



SWECO SINGLE STAGE CUTTINGS WASH SYSTEM



NL Baroid CW4 Separate System

Type: Immersion wash, 1 stage, with 1% aqueous CW4.

Cuttings are washed (by sluicing them with a 1% aqueous solution of CW4) from the solids control equipment to a double-deck shaker unit. Washed cuttings are discharged overboard whilst screen underflow falls into an 'in use' circulating tank. When spent, the wash fluid is transferred to a holding tank where a sludge settles out leaving a clear aqueous layer on top. A second circulating tank, meanwhile, supplies wash fluid to wash the cuttings. The sludge is claimed returnable to the active mud system and the clear aqueous layer is topped up with CW4 and seawater, then returned to the first circulating tank.

Answers to Questions.

Note only limited data are available on this system. One system was purchased for installation on a UK Sector North Sea platform but it is not thought to have been used.

1. CAPITAL COSTS

   Not known.

   a. Could be fitted on either.

   b. Designed for use in UK Sector (5% wet wt limit in mind).

   c. Yes.

   d. Used during drilling with oil-based muds.

   e. Not known - screens, pumps, etc. can be changed as required.

2. MAINTENANCE COSTS

   Not known.

   a. Not known - depends on severity of use.

   b. Not known.

   c. Relatively easy (screens, pumps, cyclones, 50 bbl tanks), bulky (70-80 bbl holding tank).

   d. None, if single screen systems, 50% if tandem shaker used.

3. SYSTEM EFFICIENCY

   a. No data available.

   b. Insufficient data to predict recovery.

4. OPERATIONAL CONSIDERATIONS

a. 8 tonnes/hour oily cuttings for a single shaker unit, 16 tonnes/hour for tandem shaker unit.

b. System would need checking at intervals similar to solids control.

c. Solids control engineer could oversee.

d. 1 man per shift.

e. Continuous process. No surge facilities. Storage required for chemicals (it is estimated that 2-3 bbl/day of CW4 surfactant will be used).

f. 50 kW for a unit including pumps and a tandem shaker unit.

5. SAFETY CONCERNS

a. Unlikely.

b. Low hazard - though properties of concentrated CW4 unknown.

c. Low hazard - though properties of concentrated CW4 unknown.

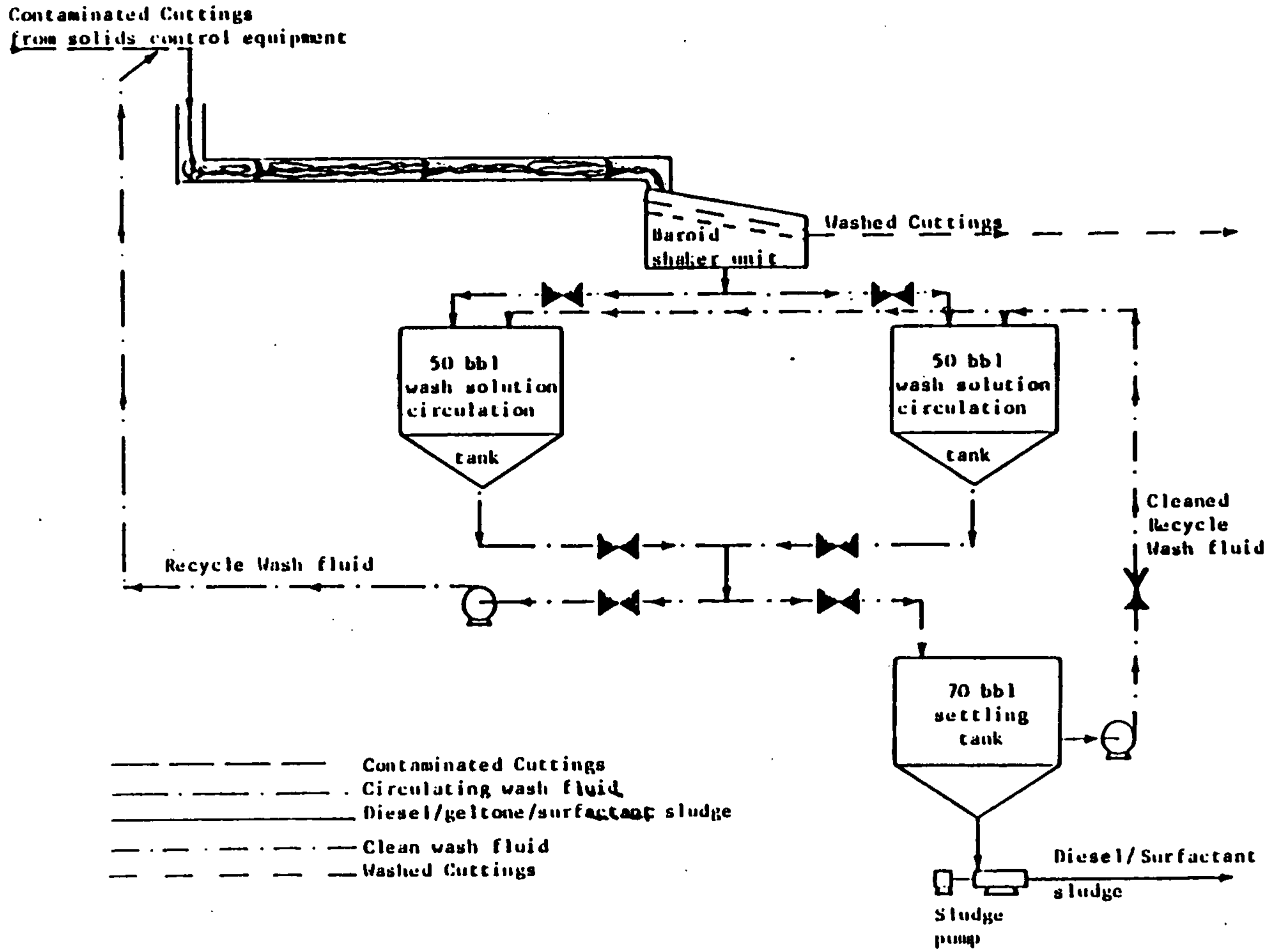
d. None (unless separated sludge is burned rather than recycled to mud system).

6. SPACE AND STORAGE

a. Space required for 2 x 50 bbl circulation tanks, 1 x 70-80 bbl setting tanks, single or tandem shaker unit, 3 or 4 pumps and (optionally) cyclones and a centrifuge.

b. Tanks described above - (storage for concentrated CW4 surfactant would also be required).

c. Estimated 30 tonnes wet.



NL BAROID C/W SEPARATE SYSTEM

Thomas Broadbent and Sons Ltd. Base Oil Centrifuge Wash System

Type: Immersion wash (centrifuge) with base oil

References 22, 23, 24.

Cuttings are sluiced from the solids control equipment into an agitated wash tank containing mud base oil. The resulting slurry is pumped to a primary decanting centrifuge which yields treated cuttings (flushed overboard) and base oil contaminated with fines. The base oil is then treated in a secondary high speed decanting centrifuge which yields clean wash fluid for recycle and an oily fines sludge, which can be stored, combusted or discharged overboard with the larger cuttings. When spent, it is claimed that the wash fluid and oil recovered from the cuttings may be returned to the active mud system (published data indicates this may be acceptable - see Ref. 22).

This system has undergone relatively extensive testing and has been purchased for installation on at least 4 Norwegian and 1 UK offshore installations. Note that Thule and Drexel (UK) have also marketed similar systems based on a centrifuge.

Answers to Questions.

1. CAPITAL COSTS

Systems are available to treat up 4, 12 and 50 tonnes/hour of oily cuttings feed, costing as follows:

$275,000 for 4 t.p.h. system.
$450,000 for 12 t.p.h. system.
$650,000 for 50 t.p.h. system.

a. Either.

b. Is used at present in UK and Norwegian Sectors of North Sea (must meet a limit of 100 g oil/kg dry (retorted) cuttings in the Norwegian Sector).

c. Yes, as long as module containing system is not built into topsides.

d. Used during drilling with oil-based muds.

e. Not known - insufficient published data.

2. MAINTENANCE COSTS

Not known.

a. Not known - probably similar to Broadbent aqueous wash system. Plus wash fluid needs changing when it reaches a certain viscosity.

b. Not known - replacing centrifuge internals is costlier than replacing a screen.

c. Smaller centrifuges, pumps and tanks should be relatively easy, larger units are bulky.

d. If only one primary centrifuge is installed, the system cannot operate if this is being maintained (short-term operation should be possible during shut-down of the secondary centrifuge.

3. SYSTEM EFFICIENCY

a. Recent test data (pilot scale and full scale operating data on Norwegian platforms) indicate that the system should yield between 7 and 13 g oil/100 g dry cuttings. Broadbent claims a full scale system should retain oil on cuttings levels at <10 g oil/100 g dry (retorted) cuttings on a well-averaged basis.

b. Pilot testing offshore indicates that around 500 bbl/well of oil could be recovered from the cuttings (Ref. 22).

4. OPERATIONAL CONSIDERATIONS

a. 3 sizes are available to process 4, 12 or 50 tonnes/hour of oil cuttings feed.

b. Insufficient data, but it would be prudent to check at intervals similar to solids control system.

c. Solids control engineer could oversee.

d. Broadbent claims the solids control operators could manage the system.

e. Continuous process. Catch tank and wash tank will smooth cuttings flow. Base oil wash fluid would be stored with bulk base oil.

f. Energy requirements are as follows:

Unit	Power rating of complete system	Power rating of primary/ secondary centrifuge
4 t.p.h.	130 kW	55/55 kW
12 t.p.h.	200 kW	110/55 kW
50 t.p.h.	480 kW	350/55 kW

5. SAFETY CONCERNS

a. Unlikely.

b. 'Low-toxicity' base oil should be handled with caution, fumes.

c. Base oil in open tanks presents possible hazard (though flash point is usually 1 1/2 to 2 times that of diesel).

d. If the sludge from the secondary centrifuge is to be disposed of by combustion, this creates a potential for incomplete combustion (the amount of sludge produced is not known).

6. SPACE AND STORAGE

a. The units in the system could be supplied individually or mounted on a single skid, as follows:

Unit t.p.h.	Dimensions of Complete System m (L x W x H)	Dimensions of Primary/Secondary Centrifuge Units m (L x W x H)
4	6 x 5.5 x 3	2.75 x 2.41 x 1.20/2.75 x 2.41 x 1.20
12	7 x 7 x 3	4.20 x 3.08 x 1.55/2.75 x 2.41 x 1.20
50	8 x 9 x 3.5	5.74 x 3.63 x 1.78/2.75 x 2.41 x 1.20

b. The following tanks are used in the systems

Unit	4 t.p.h.	12 t.p.h.	50 t.p.h.
Wash tank	12	25	38
Primary Catch tank	25	50	75
Secondary Catch tank	50	50	75
Sludge Catch tank	50	50	75

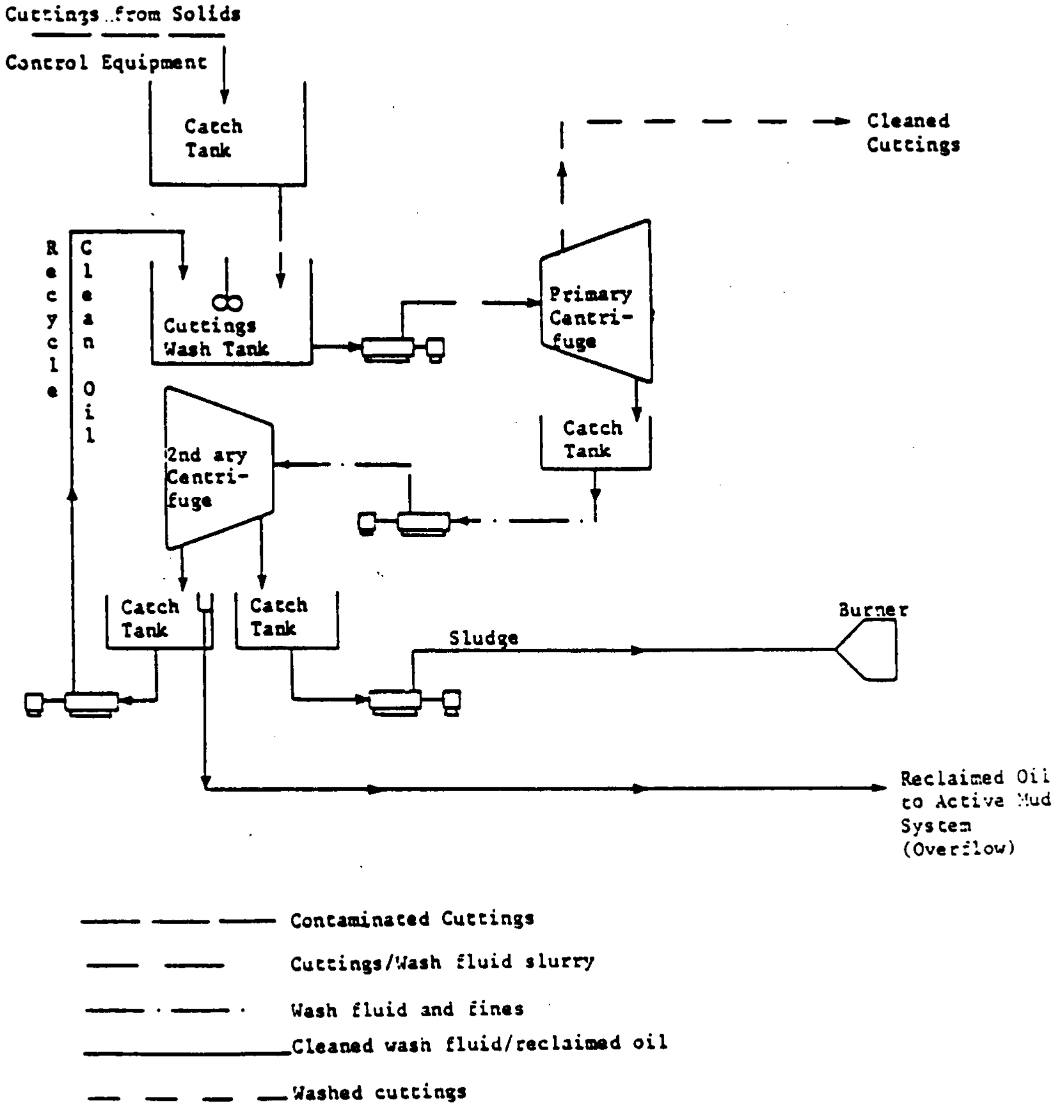
Capacity of the initial cuttings surge tank depends on operators' specification. Bulk wash fluid storage would be with the mud base oil.

c.

Unit t.p.h.	Weight of System dry (tonnes)	Weight of System wet* (tonnes)	Weight of 2 Centrifuges (tonnes)
4	40	52	7.0
12	65	90	14.5
50	90	125	26.0

* estimated.

THOMAS BROADBENT BASE OIL CENTRIFUGE WASH SYSTEM



Dresser Swaco Wash Drum/Centrifuge System

Type: Immersion wash (centrifuge) with aqueous detergent.

Cuttings are sluiced into a washing drum with aqueous detergent solution. Washed cuttings are discharged overboard whilst contaminated wash fluid is treated in a two phase decanting centrifuge for fines removal (fines are discharged overboard) and in the three phase disc stack centrifuge. The disc stack yields oil (for, it is claimed, recycle to the active mud system), cleaned wash fluid and ultra-fines (colloidals) (for discharge overboard).

Systems have been installed on 2 installations (1 rig, 1 platform) for use in the Norwegian Sector of the North Sea, and it is thought that an order has been placed for 2 more systems to be installed on a new platform.

Answers to Questions.

1. CAPITAL COSTS

The major items comprising the system cost the following:

Feed pump (if required)	$ 15,000
Wash drum	$ 50,000
Decanting centrifuge	$150,000
Disc stack centrifuge	$200,000

Pumps, tanks, lines and skid-mounting the package would have to be added to these costs.

a. Either.

b. Designed for use in UK and Norwegian Sectors of North Sea (must meet a limit of 100 g oil/kg dry (retorted) cuttings in the Norwegian Sector).

c. Yes, as long as the module containing the system is not built into the topsides.

d. Used when drilling with oil-based muds.

e. Not known - insufficient published data.

2. MAINTENANCE COSTS

Not known.

a. Not known - in theory system is closed-loop, hence wash fluid should not need changing.

b. See capital costs - cost of smaller items is not known.

c. Relatively easy-though wash drum is somewhat bulky.

d. If only 1 wash drum is installed, the system could not operate when this is being maintained - short-term operation should be possible during shutdown of the other centrifuges (though the wash fluid would become rapidly contaminated).

3. SYSTEM EFFICIENCY

a. Short-term full-scale tests carried out onshore indicated a range of oil on cuttings levels from 14-50 g oil/100 g dry (retorted) feed cuttings to 1-20 g oil/100 g dry (retorted) effluent cuttings (6-96% reduction in oil content). These tests were to optimize operating parameters. Offshore operating data for the wash drum discharge only indicate reduction in oil on cuttings from 8.4-17.6 g oil/100 g dry (retorted) wash drum effluent cuttings (54.5 to 71.4 percent reduction in oil content).

b. Insufficient data to predict recovery of oil in an adequate state for recycle to the active mud system.

4. OPERATIONAL CONSIDERATIONS

a. 12.5 tonnes/hour oily cuttings.

b. Insufficient data, but it would be prudent to check at intervals similar to solids control equipment.

c. Solids control engineer could oversee.

d. Probably 1 man per shift.

e. Continuous process. No surge tank supplied. Storage required for concentrated detergent - probably supplied in drums.

f. 105.5 kW total (washing drum consumes 12 kW, decanting centrifuge - 42 kW, disc stack centrifuge - 18.5 kW, 3 pumps - 11 kW each).

5. SAFETY CONCERNS

a. Unlikely.

b. Low - though properties of detergent unknown.

c. Low.

d. Negligible.

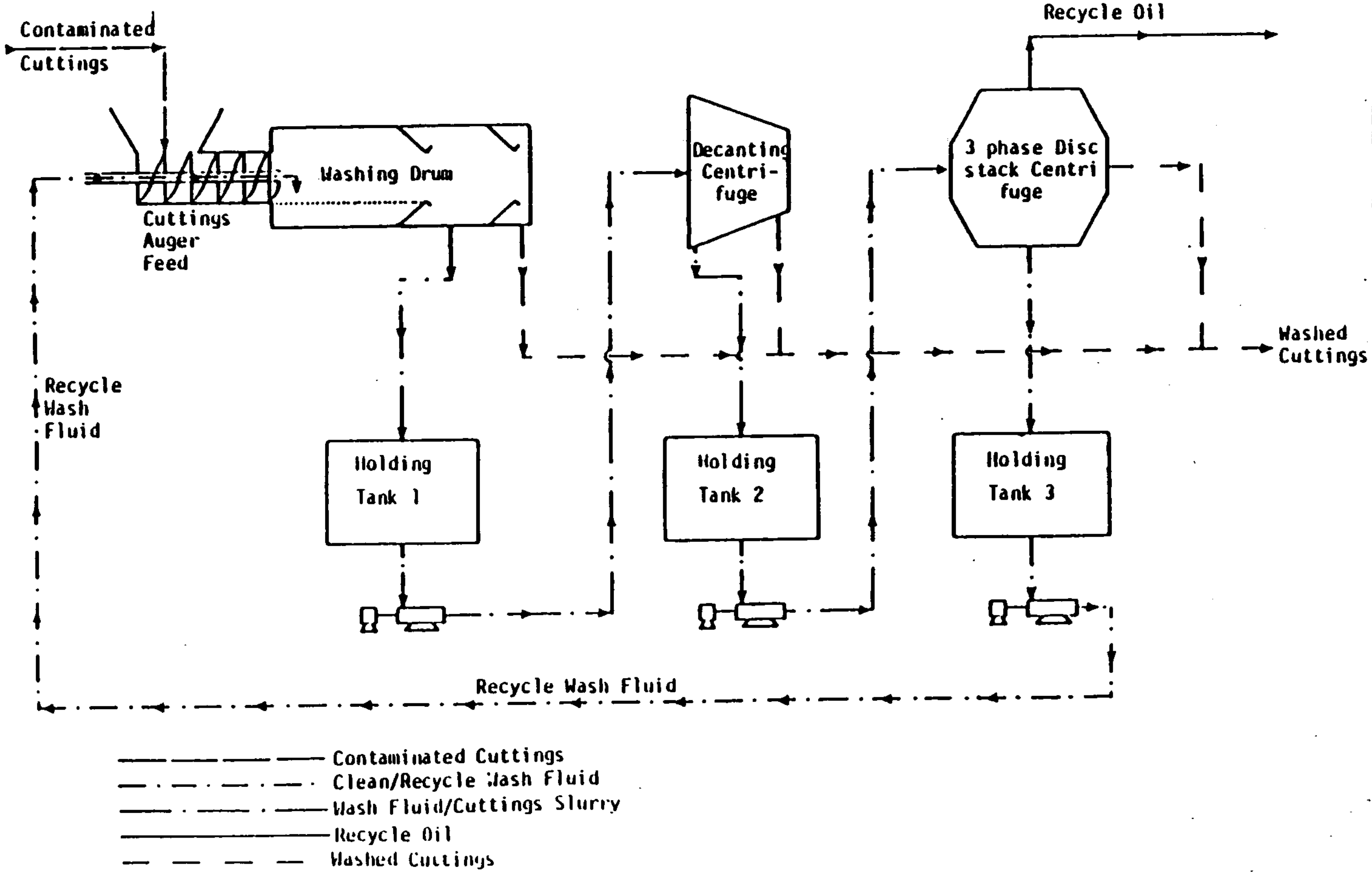
6. SPACE AND STORAGE

a and c. Individual items have the following dimensions and weights.

	Size (L x W x H) m	dry weight kg	wet weight kg
Wash drum	4.4 x 1.7 x 1.9	2500	3800
Decanting centrifuge	2.8 x 1.9 x 2.0	2610	--
Disc stack centrifuge	2.0 x 1.4 x 2.0	4616	4977
3 pumps (each)	1.7 x 0.58 x 1.4	--	853
		10 tonnes	14 tonnes

Tank size depends on operator requirements. In one example, the wash drum is placed by the shale shakers, the centrifuges are skid mounted over a similar sized skid module (6.1 x 2.4 x 2.4 m) containing pumps and tanks.

b. As stated, tank size would be chosen to operator requirements.



DRESSER SWACO WASH DRUM/CENTRIFUGE SYSTEM

Drexel Norway Wash Drum/Centrifuge System

Type: Immersion wash (centrifuge) with aqueous or base oil.

Cuttings may first be washed in an optional agitated wash tank, prior to being sluiced into a wash drum. Washed cuttings are then discharged overboard. If aqueous wash fluid is used (for optimum cuttings cleaning) the wash fluid passes to a 3 phase decanting centrifuge (where an emulsion breaking chemical may be added, if required). This yields recycle wash fluid, recycle oil (which, it is claimed, can be recycled to the active mud system) and centrifuged fines. If base oil wash fluid is used (for optimum oil recovery), the wash fluid passes to a 2 phase decanting centrifuge, yielding recycle wash fluid which, it is claimed, can also be returned to the active mud system, and centrifuged solids.

In both cases, the centrifuged solids can be passed through a band press filter then dumped. Alternatively they may be stored or combusted (depending on overall system performance).

No systems have yet been purchased for use offshore.

Answers to Questions.

1. CAPITAL COSTS

   Around $250,000 for the wash drum, 2 centrifuges and 2 tanks. A band press filter would cost around $125,000 and any chemical dosing systems would be extra.

   a. Either.

   b. System was designed with Norwegian regulations in mind (10 g oil/100 g dry (retorted) cuttings - if using 'low-toxicity' mud).

   c. Yes.

   d. Used during drilling with oil-based muds.

   e. Not known - insufficient data.

2. MAINTENANCE COSTS

   Not known.

   a. Not known.

   b. Not known.

   c. Relatively easy - though band press filter is somewhat bulky.

d. If only one wash drum is installed, the system cannot operate if this is being maintained (short-term operation should be possible during shutdown of the centrifuges (and band press filter) though the wash fluid may contaminate rapidly.

3. SYSTEM EFFICIENCY

a. Short-term onshore testing (at full-scale) showed a typical reduction in oil on cuttings of 16 g oil/100 g dry (retorted) cuttings feed down to 5.4 g oil/100 g dry (retorted) effluent cuttings. However, results were variable owing to the wide number and concentrations of detergents tested.

b. Insufficient data to predict reliably.

4. OPERATIONAL CONSIDERATIONS

a. 15.6 tonnes/hour of oily cuttings feed.

b. Insufficient data but it would be prudent to check at intervals similar to solids control system.

c. Solids control engineer could oversee.

d. 1 man per shift.

e. Continuous process. Optional wash tank act as a buffer. Storage required for concentrated detergent - would probably be supplied in drums.

f. The units in the system consume the following:

Wash drum	3 kW
Centrifuges (2 of)	35 kW each
Band press filter	3.2 kW
Mono pumps (3 of)	6 kW each
	95 kW approx.

5. SAFETY CONCERNS

a. Unlikely.

b. Low - though properties of detergent unknown.

c. Low.

d. Negligible unless oily fines sludge from centrifuge is combusted. In this case, there is potential for incomplete combustion.

6. SPACE AND STORAGE

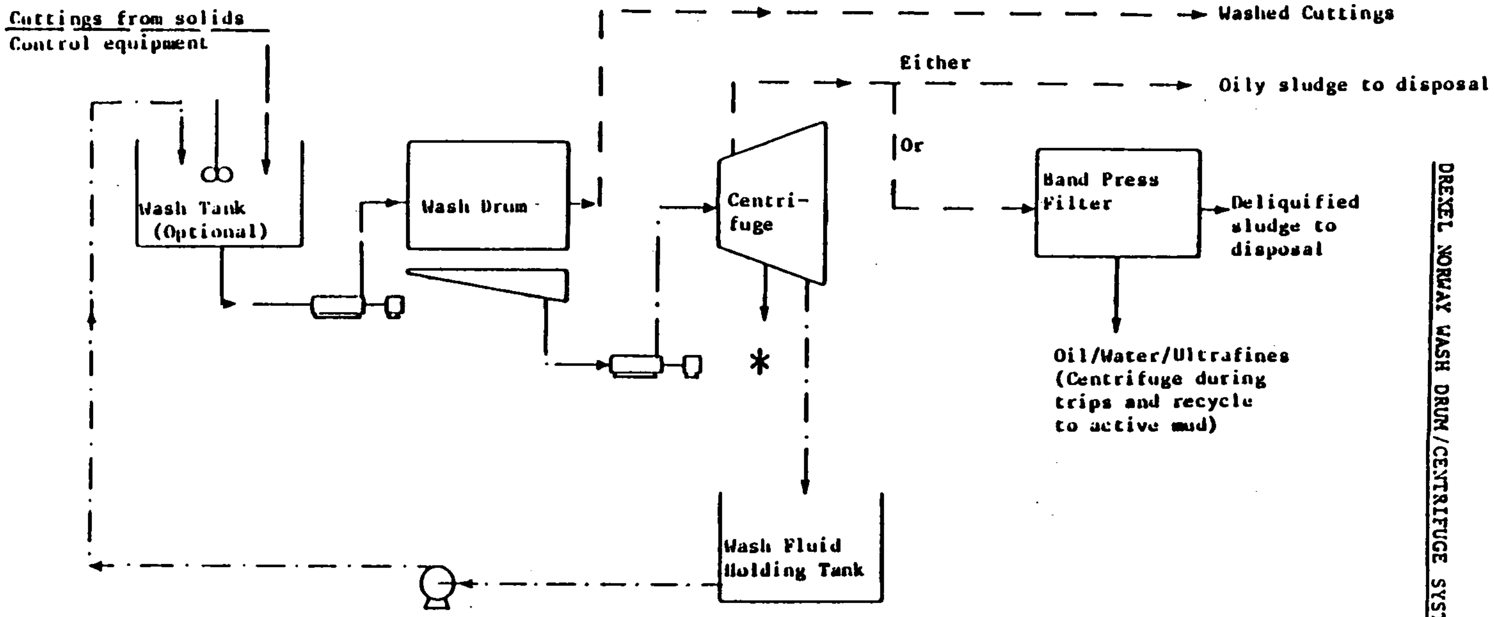
a and c. The units occupy and weigh the following:

	Dimensions (L x W x H) m	Dry weight (tonnes)
Optional agitated feed tank	2 m^3	--
Wash drum	2.50 x 1.50 x 1.44	1.0
2 centrifuges (each)	2.27 x 1.34 x 1.00	2.2
Optional band press filter	4.20 x 2.40 x 2.00	7.5
Wash drum liquid catch tank	1.5 m^3	--

The tanks, pumps and wash fluid add 10 tonnes to this figure giving a total of 17.5 tonnes with the band press filter.

b. As seen, the feed tank holds 12 bbls (2 m^3), the catch tank holds 9 bbls (1.5 m^3).

DREXEL NORWAY WASH DRUM/CENTRIFUGE SYSTEM



——— ——— ——— Contaminated Cuttings

—— —— Cuttings/Wash fluid slurry

—— · —— Wash fluid and fines

— · — · — Clean wash fluid

————————- Predominanatly oil

— — — Washed cuttings

* Third phase stream of oil for recycle to the active mud system (occurs in aqueous wash fluid system).

Drexel Equipment (UK) Ltd. Multistage Wash Systems

Type: Wash/immersion: 2 or 3 stages (diesel/seawater; diesel/seawater/seawater)

References 5, 13, 16.

Two-Stage Wash System

Cuttings are first washed by immersion in an agitated tank containing diesel. The resulting slurry is pumped over a shaker screen then through cyclones and a two-phase decanting centrifuge. Wash fluid is recycled whilst the solids fall into an agitated tank containing seawater. The resulting slurry is pumped over a shaker screen through cyclones and a three-phase decanting centrifuge. This centrifuge yields fines (which are discharged overboard along with all other solids), recycle seawater wash fluid and a third phase of diesel wash fluid for recycle. Excess oil is claimed returnable to the active mud system.

Three-Stage Wash System

This system is essentially similar. Cuttings are first washed in diesel then dried on a shaker screen and in a two-phase centrifuge. Diesel is recycled, cuttings enter the second stage where they are washed in seawater then dried on screens and in cyclones. Seawater is recycled, cuttings enter the third stage where they are again washed in seawater then dried on screens and in a three-phase centrifuge. The cuttings are then discharged overboard and the carry over diesel in the aqueous wash fluid is separated out in the three-phase centrifuge.

Two-stage systems were installed on BP's Magnus platform and on a rig drilling in the UK Sector of the North Sea. Neither system has been used as originally intended. A three-stage system was purchased for the Hutton platform (Conoco) but is not installed.

Answers to Questions

1. CAPITAL COSTS

   $350,000 for 2 stage system.
   $500,000 for 3 stage system.

   a. Could be installed on either.

   b. Designed for UK Sector of North Sea (5% wet wt limit in mind).

   c. Yes, as long as module containing system is not built into topsides.

   d. Used during drilling with oil-based muds.

   e. Not known - individual items (e.g., pumps, screens, etc.) can be replaced as required.

2. MAINTENANCE COSTS

Not known.

a. Not known.

b. Not known.

c. Relatively easy, although systems supplied in skid mounted module appear cramped.

d. System contains 2 trains, hence can operate at 50% capacity.

3. SYSTEM EFFICIENCY

a. Varous short-term tests have been conducted on the systems yielding residual oil on cuttings of 5% wet wt or less.

b. Insufficient data to predict recovery.

4. OPERATIONAL CONSIDERATIONS

a. 10 tonnes/hour of oily feed.

b. System would need checking at intervals similar to solids control equipment.

c. Solids control engineer could oversee.

d. 1 man per shift.

e. Continuous process. First-stage diesel wash acts as buffer. No chemical requirement.

f. 112 kW for 2 stage system.
165 kW for 3 stage system.

5. SAFETY CONCERNS

a. Unlikely.

b. Dermatitis and fumes from diesel wash fluid.

c. Diesel in open tanks presents possible hazard.

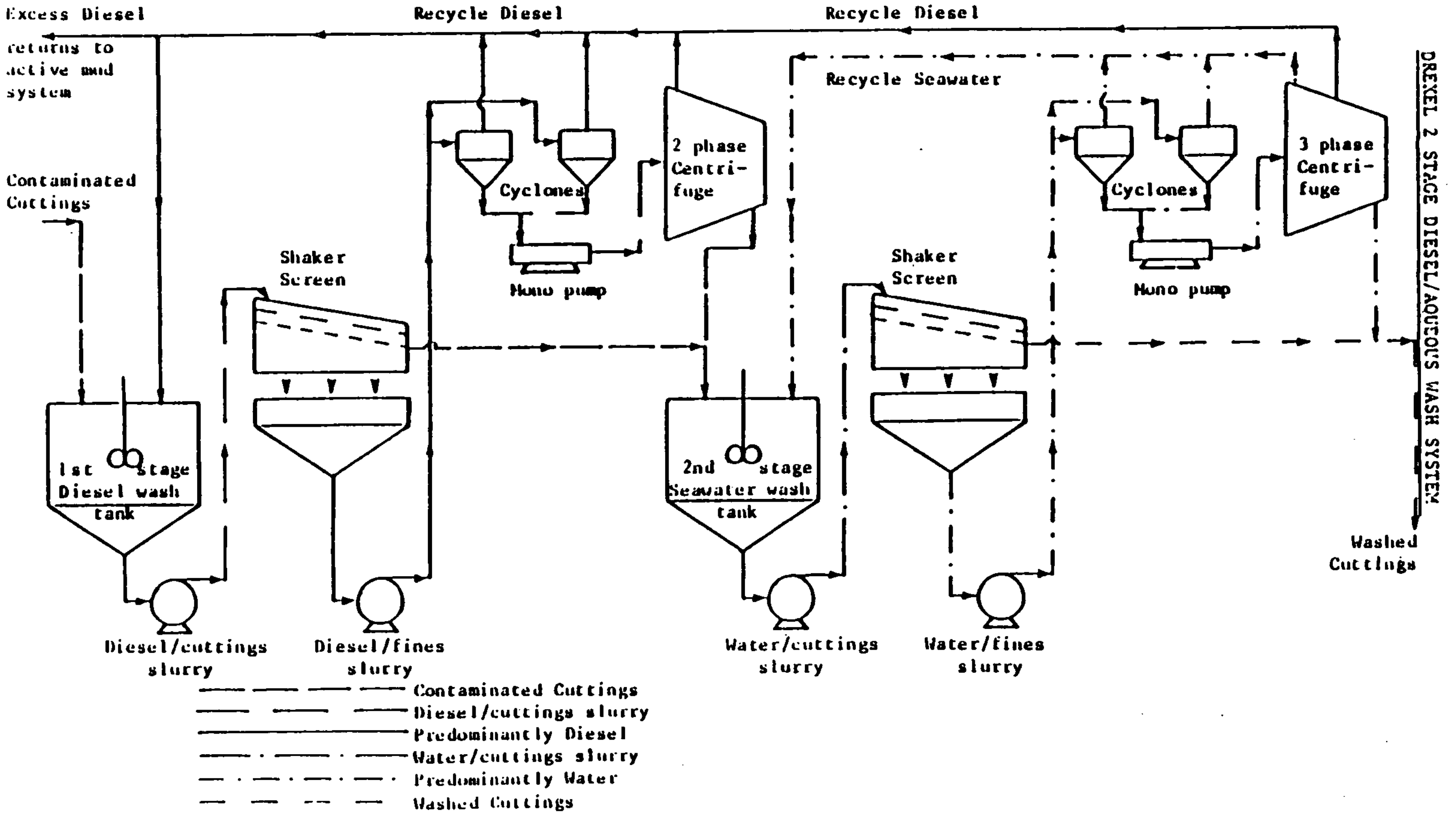
d. None other than fumes (or if spent/recycle diesel were to be burned).

6. SPACE AND STORAGE

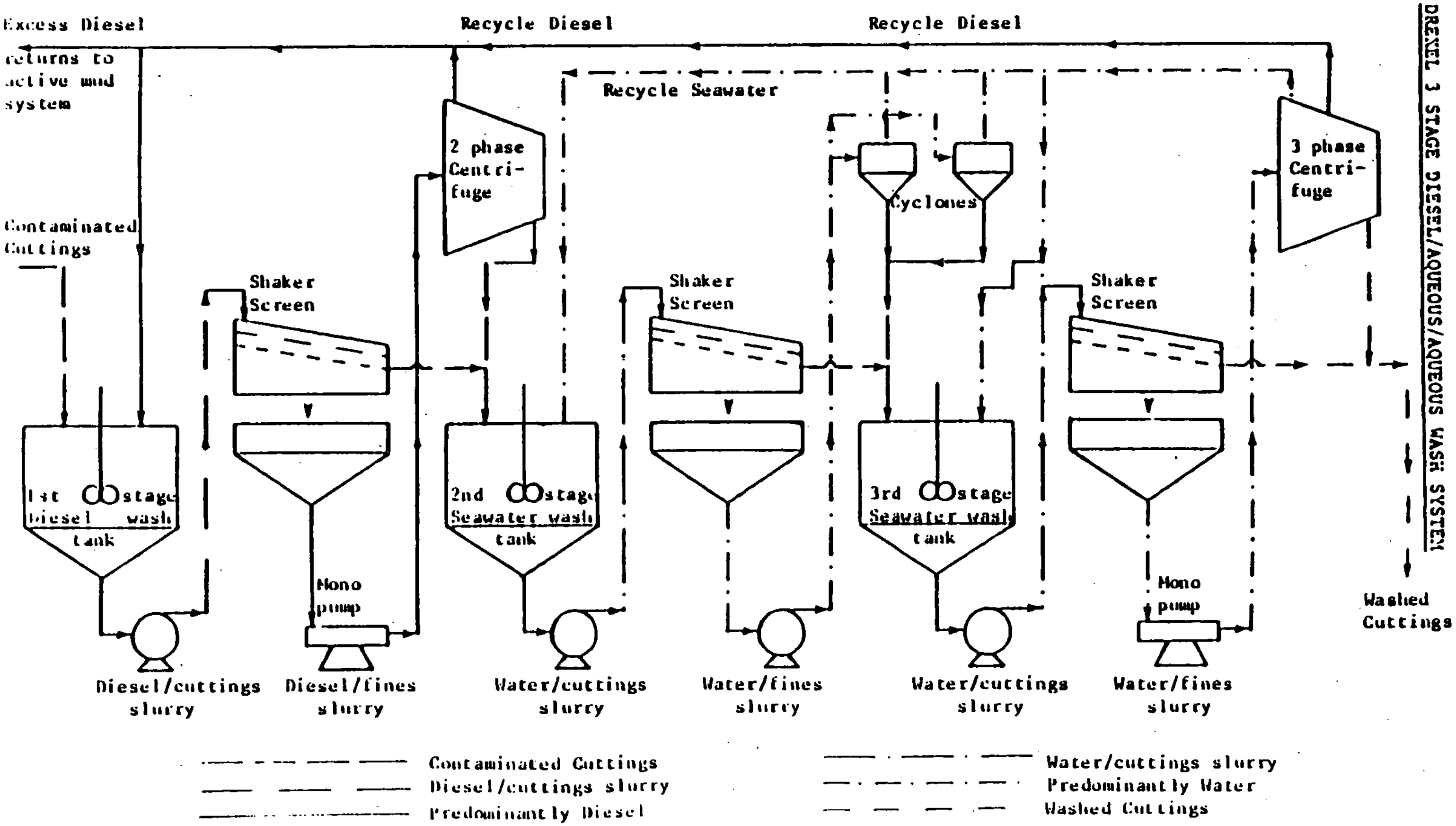
a. Equipment usually supplied in skid mounted package having following dimensions (it could also be mounted separately)
6.5 x 4.5 x 4.65 m (L x W x H) for 2 stage system.
9.0 x 6.3 x 4.3 m (L X W x H) for 3 stage system.

b. All tanks are housed within modules (dimensions given above).

c. 24.5 tonnes dry, 35.8 tonnes wet for 2-stage system
27 tonnes dry, 42 tonnes wet for 3-stage system.



DREXEL 2 STAGE DIESEL/AQUEOUS WASH SYSTEM



DREXEL 3 STAGE DIESEL/AQUEOUS/AQUEOUS WASH SYSTEM

Thomas Broadbent and Sons Ltd. Aqueous Centrifuge Wash System

Type: Centrifuge wash, aqueous solution

Reference 17.

Cuttings are sluiced into a screen bowl centrifuge with aqueous detergent solution. Centrifuged cuttings are discharged overboard. The dirty wash fluid is pumped into a smaller three-phase solid bowl centrifuge where a flocculant is added. This unit yields recycle wash fluid, an oily fines sludge (which must be stored or disposed of by combustion) and a third-phase or oil which, it is claimed, can be recycled to the active mud system.

A system has been installed on Mobil's Beryl B platform in the UK Sector of the North Sea but is at present being modified for reclaiming low toxicity mud (see information on Broadbent Base Oil Centrifuge Wash System).

Answers to Questions.

1. CAPITAL COSTS

   The units can be supplied to treat 2-5, 5-12, 12-25 tonnes/hour of oily feed - hereafter referred to as the 4, 10 and 22 tonne/hour units respectively.

   $260,000 for 4 t.p.h. unit
   $350,000 for 10 t.p.h. unit
   $500,000 for 22 t.p.h. unit

   a. Could be fitted on either.

   b. Designed for use in UK Sector of North Sea (with 5% wet wt limit in mind).

   c. Yes, as long as skid mounted modules are not built into topsides. Larger modules may prove awkward to move in one piece.

   d. Used when drilling with oil-based muds.

   e. Insufficient published data - depends on rate or wear of centrifuge (and pump) interiors - would have to replace ceramic tiling in centrifuges as required.

2. MAINTENANCE COSTS

   Not known.

   a. Daily checks - top up chemical storage tanks, monthly checks - lubrication, tightness of bolts, etc. It is claimed that major maintenance (e.g., replacement of worn parts) would be required every two years.

b. Not known, but replacement of large centrifuge internals is costlier than replacement of screens.

c. Pumps, tanks, the smaller centrifuges and ancillary equipment should be relatively easy to handle, larger centrifuges will be bulky.

d. If primary centrifuge is shut down, system cannot be operated. System could operate for short periods without the secondary centrifuge.

3. SYSTEM EFFICIENCY

a. A 2.2 t.p.h. pilot plant yielded the following results during short-term tests.

12-18% wet wt oily clay gumbo feed reduced to 3-4 g oil/100 g dry cuttings effluent, 12-22% wet wt oily clay shales cuttings feed reduced to 5.5-6.5 g oil/100 g dry cuttings effluent, 26% wet wt Marl feed reduced to 8-8.5 g oil/100 g dry cuttings effluent. All results were analyzed by modified Dean and Stark measurement.

b. Pilot testing indicates only a small recovery of oil - around 0.68-1.36 litres of oil/tonne of cuttings treated.

4. OPERATIONAL CONSIDERATION

a. See 1.

b. Insufficient data but it would be prudent to check at intervals similar to solids control system.

c. Solids control engineer could oversee.

d. Broadbent claims a full-time operator is not required.

e. Continuous process. Cuttings are washed into a cuttings trough to smooth surges (prior to entering primary centrifuge). Storage is required for the oil sludge produced from the secondary centrifuge (to allow sufficient to build up prior to combustion), also for the detergent and flocculent chemicals (for which tanks and metering pumps can be supplied).

f. 130 kW for 4 t.p.h. unit
150 kW for 10 t.p.h. unit
400 kW for 22 t.p.h. unit

5. SAFETY CONCERNS

a. Unlikely.

b. Low - though flocculant is an extreme slip hazard. Both flocculant and detergent are stated to be very low toxicity.

c. Low.

d. A sludge (containing oil, water and solids in roughly equal amounts) comprising around 18 wt % of the feed requires disposal - probably by combustion. This creates a potential for incomplete combustion.

6. SPACE AND STORAGE

a. The system could be supplied mounted either on one skid or on individual skids for fitting around existing equipment. The one-skid system has the following dimensions:

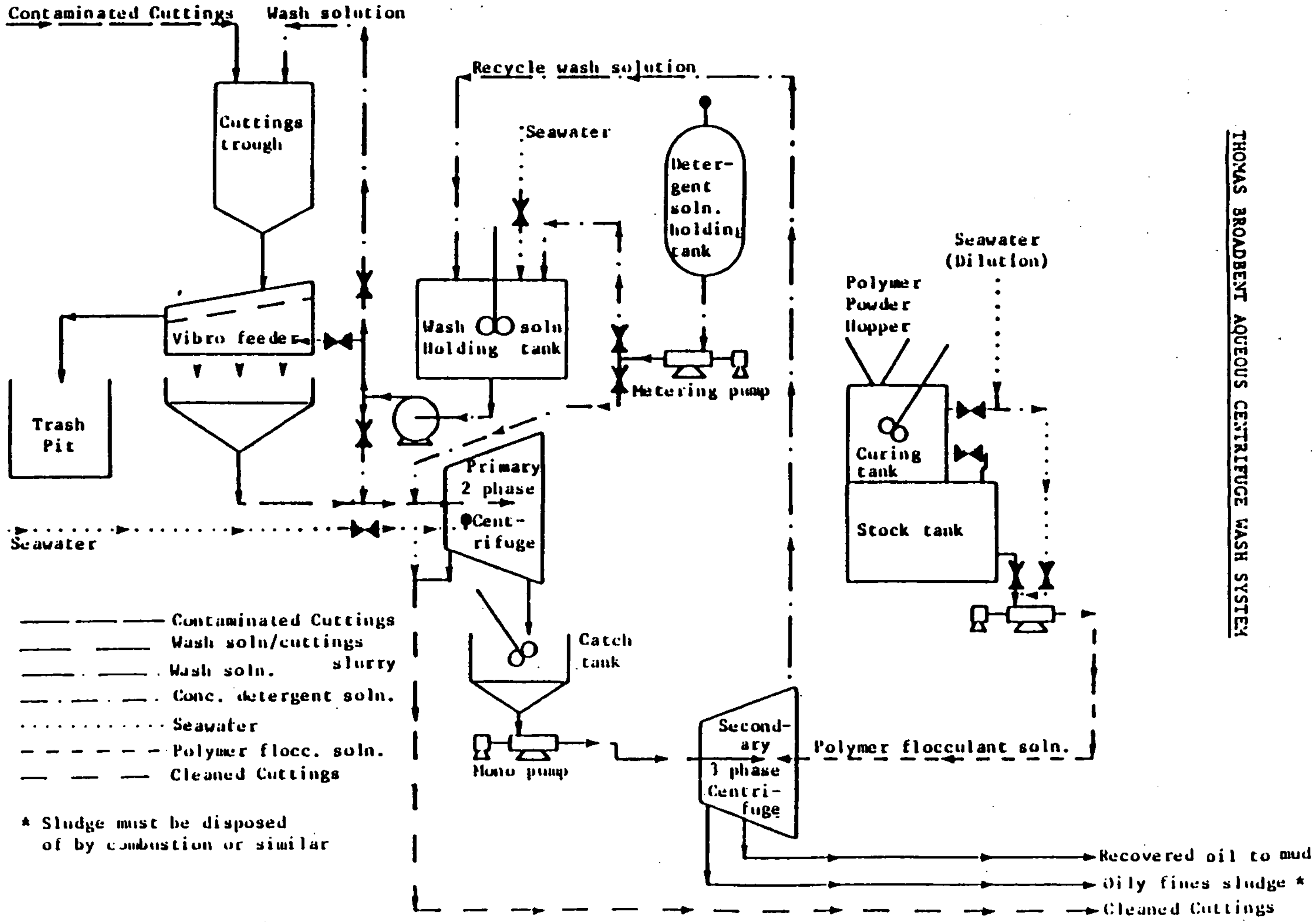
6.5 x 6.5 x 1.2 m (L x W x H) for 4 t.p.h. unit
8.5 x 8.5 x 1.6 m (L x W x H) for 10 t.p.h. unit
12.5 x 12.5 x 1.8 m (L x W x H) for 22 t.p.h. unit

Note the height corresponds to maximum equipment height.

b. The following storage tanks are used with the system (litres)

	4 t.p.h. unit	10 t.p.h. unit	22 t.p.h. unit
Wash soln. holding tank	5000	7500	7500
Catch tank	500	500	1000
Detergent tank	750	2000	3500
Polymer stock tank	100	250	5000

c. 35 tonnes wet for 4 t.p.h. unit
45 tonnes wet for 10 t.p.h. unit
75 tonnes wet for 22 t.p.h. unit



THOMAS BROADBENT AQUEOUS CENTRIFUGE WASH SYSTEM

SOLVENT EXTRACTION SYSTEMS

Sweco/FIS Trichloroethane Wash System

Type: Immersion wash, 1 stage, with solvent recycled.

Cuttings are washed in an agitated tank containing trichloroethane. The resulting slurry is pumped over two circular shaker screens (hooded to minimize escape of vapours) and oversize cuttings are then discharged overboard. Screen underflow is centrifuged to remove fines (which are discharged overboard) and the wash fluid is then recycled to the wash tank. An electrically-heated batch still processes 6-8 bbl/hour of solvent to remove oil, water and ultra-fines (which, it is claimed, may be returned to the active mud system). Distilled solvent is condensed and recycled.

Answers to Questions.

1. CAPITAL COSTS

   $170,000

   a. Could be fitted on either.

   b. Designed for UK Sector of the North Sea (with 5% wet wt guideline in mind).

   c. Yes - system would typically be supplied mounted on 3 skids.

   d. Used during drilling with oil-based muds.

   e. Not known - screens, pumps, etc., can be changed as required.

2. MAINTENANCE COSTS

   Not known.

   a. Not known - depends on severity of use.

   b. Not known.

   c. Relatively easy.

   d. Since 2 screens are available, system could run at reduced capacity during screen or other maintenance.

3. SYSTEM EFFICIENCY

   a. Levels reduced from 15 wt% to 0.7-2.3 wt% (gravimetric analysis) during short-term pilot scale test.

   b. Insufficient data to predict accurate recovery but above test data imply that over 0.9 bbls oil/tonne of cuttings treated could be recovered.

4. OPERATIONAL CONSIDERATIONS

a. 6.6-8.0 tonnes/hour of oily cuttings.

b. System would need checking at intervals similar to solids control.

c. Solids control engineer could oversee.

d. 1 man/shift.

e. Continuous process. Cuttings wash tank would act as a buffer. Storage required for make up trichloroethane (probably supplied in drums).

f. 110 kW (including the still).

5. SAFETY CONCERNS

a. Unlikely.

b. Moderate to high. Trichloroethane has a TLV (40-hour week) of 350 ppm, exposure to high concentration may lead to headaches, drowsiness and giddiness, severe exposure may lead to unconsciousness or prove suddenly fatal. The fluid is also an efficient degreaser and will remove natural grease from the skin.

c. Negligible - trichloroethane is non-flammable.

d. Low - other than fumes.

6. SPACE AND STORAGE

a. The system is mounted on 3 skids as follows:
Wash unit (tanks, screens, pumps, etc.) - 5.8 x 3.1 x 3.8 m (L x W x H)
Centrifuge - 3.2 x 1.6 x 2.2 m (L x W x H)
Still, condenser and control unit - 2.8 x 2.2 x 3.1 m (L x W x H)

b. Tanks hold the following:
Wash tank (A)* - 21 bbl max.
Screen unders hold tank (B)* - 22.5 bbl max.

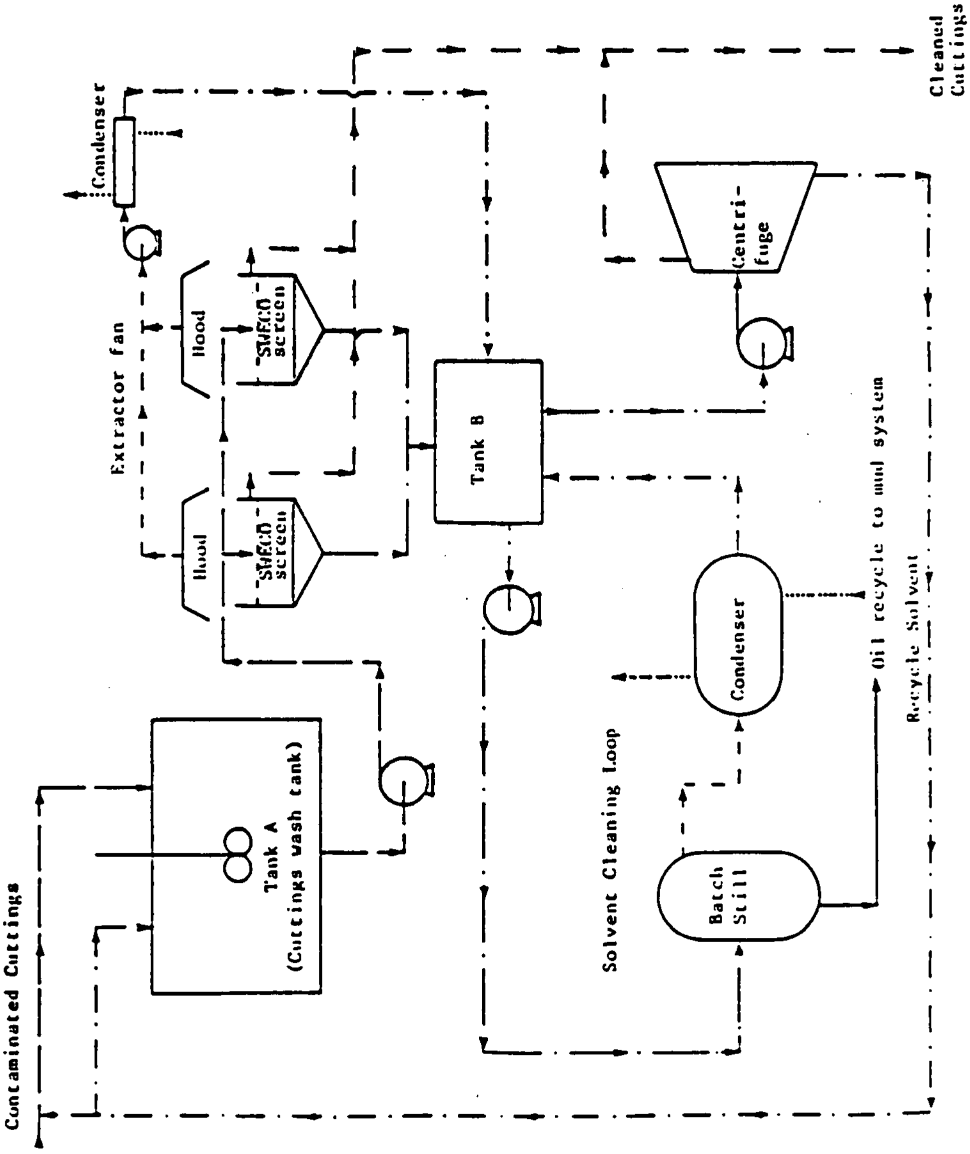
* See flow diagram previously supplied.

c. 30 tonnes dry, 40 tonnes wet (approx.).

SWECO/FIS TRICHLOROETHANE WASH SYSTEM

FLOWLINE INDEX FOR SWECO TRICHLOROETHANE SYSTEM (FIGURE 2.8)

——— ——— ——— ——— Contaminated Cuttings
—— · —— · —— · —— · Trichloroethane solvent
———— · ———— · ———— Solvent/cuttings slurry
– – – – – – – – – Solvent vapour
·································· Cooling water
— — — — Cleaned Cuttings



Critical Fluid Systems Inc. Supercritical Fluid Leaching Process

Type: Immersion wash with diesel, followed by CO_2 leaching. Solvent Recycled.

References 5, 7.

This is a semi-continuous process where cuttings are crushed, slurried with diesel and pumped to one of two batch pressure leaching vessels. Excess diesel is drained off then supercritical CO_2 (Freon and Propane may also be considered) is pumped through the vessel to extract the remaining oil/mud. The oily CO_2 is recovered by three-stage distillation. Cuttings are flushed from the extractor with seawater and discharged overboard. At the same time an extraction cycle is commencing in the second vessel. Recovered oil is, it is claimed, recycled to the active mud system.

This system at present is a prototype. These data are for a system using CO_2 solvent proposed for use in the UK Sector for the North Sea.

Answers to Questions.

1. CAPITAL COSTS

   Unclear - Ref. 5 gives $500,000

   a. Unit could conceivably be fitted on either, space/weight availability permitting.

   b. Proposal encompassed UK and Norwegian Sectors of the North Sea.

   c. Yes.

   d. Would be used during drilling with oil-based muds.

   e. Not known - roll crusher and pumps would probably require replacement at regular intervals.

2. MAINTENANCE COSTS

   Not known.

   a. Not known.

   b. Not known.

   c. Relatively easy, though some of the larger modules are somewhat bulky.

   d. Since unit has 2 extractor columns and a surge tank, unit could operate at reduced capacity.

3. SYSTEM EFFICIENCY

   a. Bench-testing indicated residual oil levels of < 0.25 wt% (method of analysis not stated).

b. Insufficient data to predict additional recovery.

4. OPERATIONAL CONSIDERATIONS

a. 3.2-4.5 tonnes/hour oily cuttings feed.

b. Until proven, system would require constant supervision - particularly important during loading/unloading of extractor columns.

c. Specially trained engineer and operators would be required.

d. Not evaluated but certain to be 1 man per shift or more.

e. Semi-continuous process - each column would be sized for 5 1/2 minute extraction cycles, leaving 5 1/2 minutes for loading/unloading. Slurry tank acts as buffer. Storage for make up CO_2 required (probably in liquid form).

f.

Compressor (3)*	241.6 kW
Compressor (4)*	4.5 kW
Compressor (5)*	3.0 kW
Monopump	7.4 kW
Roll crusher	22.3 kW
Miscellaneous pumps	11.2 kW
	290.0 kW TOTAL

*See flow diagram previously supplied.

5. SAFETY CONCERNS

a. Pressurized liquefied gas system operating at 2250 psi and 50°C poses hazard in event of severe failure of any pressure vessel or line. If system utilized propane, pressure would be lowered but explosion hazard would be introduced. Freon appears to pose the lowest hazard.

b. Low for CO_2. Propane and Freon 12 are of low toxicity except at high concentrations where the former affects the central nervous system, the latter exerts a narcotic effect.

c. Low for CO_2 and Freon, significant for propane. Diesel is stored in enclosed tanks, reducing this hazard.

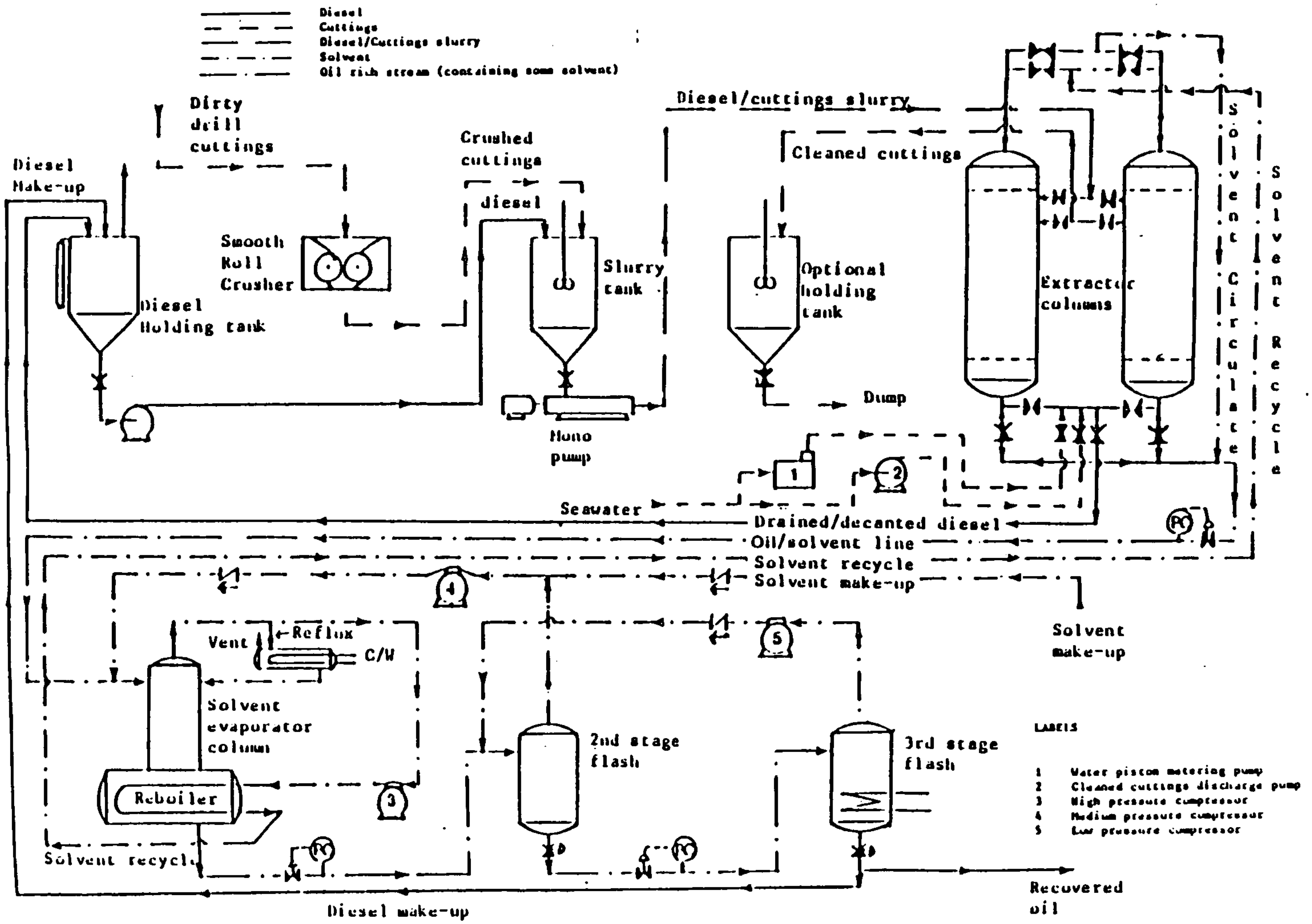
d. Low for CO_2 and propane. Freon has caused concern in the U.S. regarding its reactivity with ozone.

6. SPACE AND STORAGE

a and c. The system would be supplied on a number of skids, sizes and dry weights as given below:

Equipment on skid	Dimensions L x W x H (metres)	Dry Weight (tonnes)
Diesel hold tank and transfer pump	2.0 x 1.5 x 2.4	1.24
Smooth-roll crusher	1.8 x 0.9 x 1.2	0.73
Slurry tank and mono pump	2.4 x 1.5 x 2.7	1.86
Clean cuttings tank and water pumps	2.4 x 1.5 x 2.4	2.27
Extractor columns	2.7 x 2.0 x 2.4	3.09
Evaporator	3.7 x 2.0 x 3.7	7.19
2nd and 3rd stage flash drums and compressors	2.0 x 1.7 x 2.1	1.55
Control panel	1.2 x 0.6 x 2.1	0.18
Vapour-recompression compressor	1.4 x 0.7 x 2.0	3.68
Piping, electrical and instrumentation	--	2.27
TOTAL	30 m^2 deck space	24

b. In addition to above, storage is required for make-up solvent.


CRITICAL FLUIDS SUPERCRITICAL FLUID LEACHING PROCESS

Hughes Drilling Fluids CREW System

Type: Thermal distillation, batch process

References 5, 18, 19, 20.

This is a batch process. Cuttings are stored in a buffer storage tank and a batch is fed into the retort barrel where the cuttings are ground down and heated to 350°C under a vacuum of -0.96 bar. Vapours distill off, are cleaned in a heated cyclone (to remove fines) and then are condensed, it is claimed, for recycle to the active mud system. At the end of the (20 minute) distillation, all solids are discharged overboard. Total cycle time is 30 minutes.

This system has been installed on Marathon's Brae A platform but has not been used, owing to the introduction of 'low toxicity' oil-based muds. It is thought that Hughes no longer markets the system.

Answers to Questions.

1. CAPITAL COSTS

   $1.0-1.5 million for a processor unit and control unit plus $1.0 million per additional processor (2-3 processors would usually be required).

   a. Size and weight constraints probably limit the system to a production platform.

   b. Not sure, but thought to have been designed to meet legislation governing North Sea Platforms.

   c. Yes, as long as modules containing the system are not built into topsides.

   d. Used during drilling with oil-based muds.

   e. Not known.

2. MAINTENANCE COSTS

   Not known.

   a. Not known.

   b. Not known.

   c. Not known - no items appear unmanageable.

   d. Each processor would have to be shut down completely for maintenance, but since more than one is likely to be required, system could operate at reduced capacity.

3. SYSTEM EFFICIENCY

a. Unit is claimed to recover 98% of all mud components and is guaranteed to reduce oil on cuttings levels to <1 wt% - testing batches of oily cuttings yielded reductions of oil on cuttings from 7.35 to 0.04 % wet wt and 14.40 to 0.12% wet wt (by gravimetric analysis) which tends to confirm this.

b. No long-term data, but if oil on cuttings levels are reduced from 25% wet wt in feed to 1% wet wt or less at 1.36 tonnes/hour feedrate*, around 2.4 bbl/hour of oil will be recovered at the expense of 370 kW.

* see 4a.

4. OPERATIONAL CONSIDERATIONS

a. The maximum throughput in physical terms is around 4 tonnes/hour. Actual capacity is governed by solids density, and oil and water loadings on cuttings. A capacity of 1.36 tonnes/hour is indicated at 25 wt% oil, 10 wt% water, 65 wt% solids.

b. Until proven, system would require almost constant supervision, particularly during loading/unloading. System is claimed to require only 2 hours per day supervision and lubrication.

c. Specially-trained engineers and operators would be required.

d. Although literature states operator requirements are nil (fully automatic system), Hughes expects at least 2 men per shift will be required until system is proven.

e. Batch process. A cuttings surge tank is required (not supplied in package).

f. Each processor consumes 290 kW to heat the cuttings. The hydraulic power packs, pumps and cooling fan consume a further 73 kW.

5. SAFETY CONCERNS

a. In the event of an explosion, damage could result.

b. As above. It is not known whether fumes may present a problem.

c. Potential fire hazard. System is equipped with automatic nitrogen blanket system for emergency shutdown.

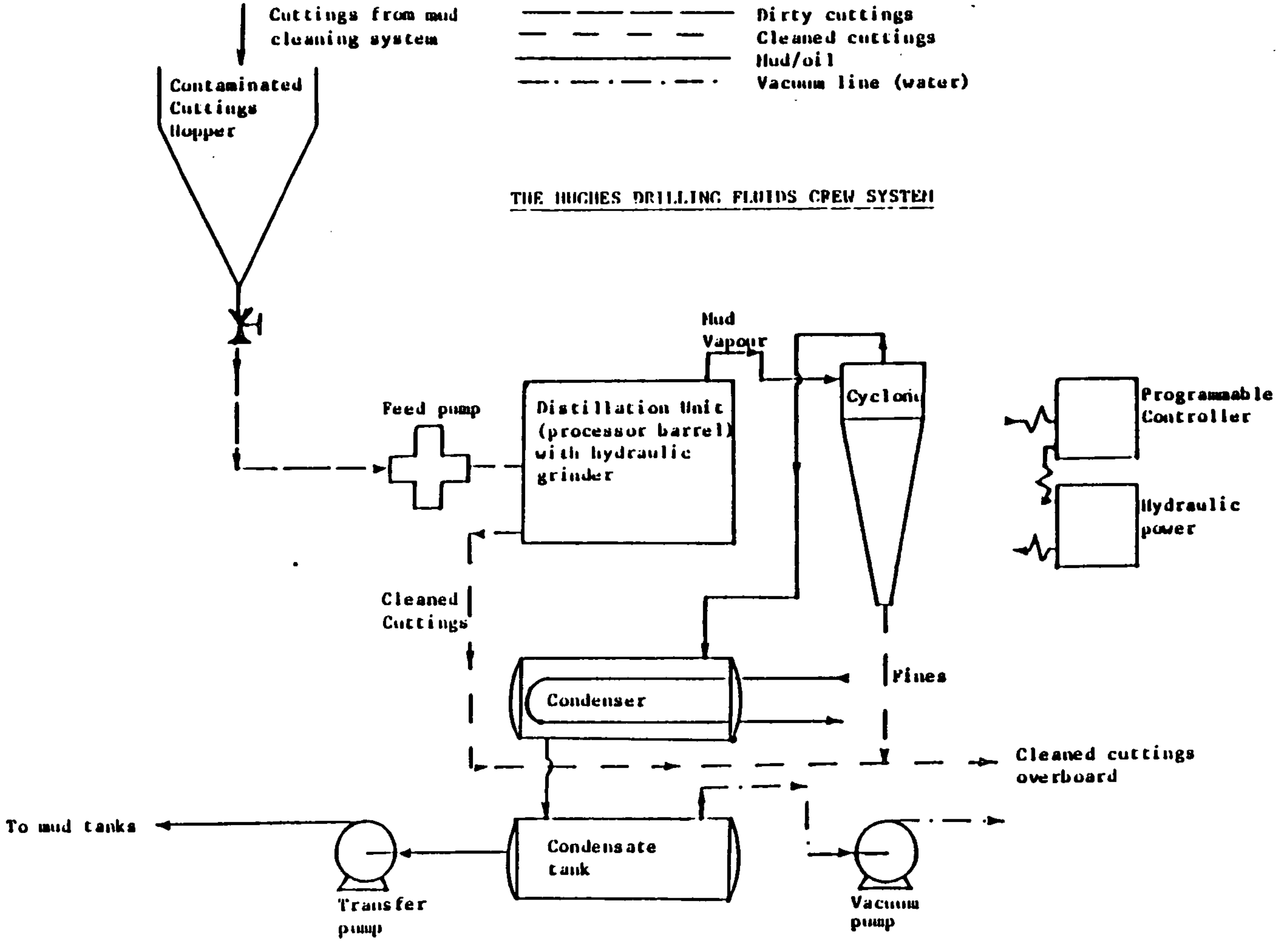
d. No.

6. SPACE AND STORAGE

a. Each processor is supplied on a skid occupying 5.00 x 2.85 x 3.15 m (L x W x H), each controller/power pack/pump skid occupies 6.40 x 2.76 x 3.35 m (L x W x H).

b. The size of the surge/buffer tank would depend on the expected maximum cuttings flowrate and on the number of processors available.

c. The processor weighs 16.5 tonnes empty, the controller/power pack/ pumps weigh 12.5 tonnes.


THE HUGHES DRILLING FLUIDS CREW SYSTEM

HUGHES DRILLING FLUIDS CREW SYSTEM

Dresser Swaco Vibrating Bed Cuttings Drier

Type: Thermal distillation, continuous process.

Cuttings are stored in a surge hopper then passed to a vibrating bed drier in which heated air (at 316°C) is blown through the cuttings as they are conveyed across the bed. The air distills off oil and water and the gaseous stream, on exiting the bed, is cleaned in a cyclone and scrubber (the latter condensing the oil and water). The oil and water are separated in an oil/water separator. Some of the oil may be used to power the air furnace, the remainder may, it is claimed, be recycled to the active mud system.

A full-scale prototype, built for further development of the unit, is thought to have been suspended.

Answers to Questions.

1. CAPITAL COSTS

   $350,000-$400,000 (or $2000/day rental).

   a. Size and weight constraints probably limit the system to a production platform.

   b. Designed in USA and was marketed in the North Sea.

   c. Possibly although size may make difficult.

   d. Used when drilling with oil-based muds.

   e. Not known.

2. MAINTENANCE COSTS

   a. Not known.

   b. Not known.

   c. Generally bulky.

   d. Each drier would have to be shut down completely for maintenance.

3. SYSTEM EFFICIENCY

   a. Tests lasting 2-3 hours at 1.7 to 3.9 tonnes per hour feed rate showed there to be less than 0.5 wt % residual oil on the cuttings (method of analysis unknown).

b. No long-term data, but if oil on cuttings levels are reduced from 25% wet wt in feed to 0.5 wt % or less at 2.35 tonnes/hour feedrate*, around 4.3 bbl/hour of oil will be recovered at the expense of 70 kW electric power and around 0.7 bbl/hour furnace fuel requirement (for an 1170 kW furnace).

* see 4a.

4. OPERATIONAL CONSIDERATIONS

a. The maximum throughput in physical terms is stated by Dresser to be 4.5 tonnes/hour. Actual capacity is governed by solids density, and oil and water loadings on cuttings.

A capacity of 2.35 tonnes/hour is indicated at 25 wt % oil, 10 wt % water, 65 wt % solids.

b. Until proven, system would require almost constant supervision.

c. Specially trained engineer and operators would be required.

d. At least 1 man per shift.

e. Continuous process. Surge hopper supplied to dampen surges. Recovered oil storage tank also supplied.

f. A heat balance on the drier unit indicates a heating requirement of around 400 kW. In addition, 70 kW electrical power is required for pumps, etc. An unlagged air furnace was found to consume 1170 kW (see 3b).

5. SAFETY CONCERNS

a. In the event of an explosion, damage could result.

b. As above. System must be well-lagged to prevent burns. It is not known whether fumes may present a problem. A potential problem for offshore use is that the system may be noisy. An unlagged test unit generated noise levels of around 85 dB which is close to the maximum permissable for an 8-hour operator shift.

c. Potential fire hazard. The unit relies on maintaining the temperature in the bed below the minimum ignition temperature of the oil. However, the fact that the unit distills oil from cuttings at a temperature above the flash point of diesel (and most low toxicity base oils) constitutes a fire and explosion risk. The system has not been safety approved. The patent for the process (UK 2,096,297, McCaskill) claims that the high volumetric air flow dilutes the organic vapour concentration in air to less than 1%. However, the lower and upper explosive limits of most diesels (and low toxicity base oils) are from around 0.7 to 5.0 or more vol %, respectively (and the auto-ignition temperature of at least one low toxicity base oil is less than the inflowing air temperature). Dresser states that their calculations and field experience indicate that the vapourized hydrocarbon level will be below the lower explosive limit, and that auto-ignition is not a problem since the actual cuttings contact area is below 200°C.

d. Low - exhaust may be slightly contaminated with fines, water vapour and oil vapour/droplets.

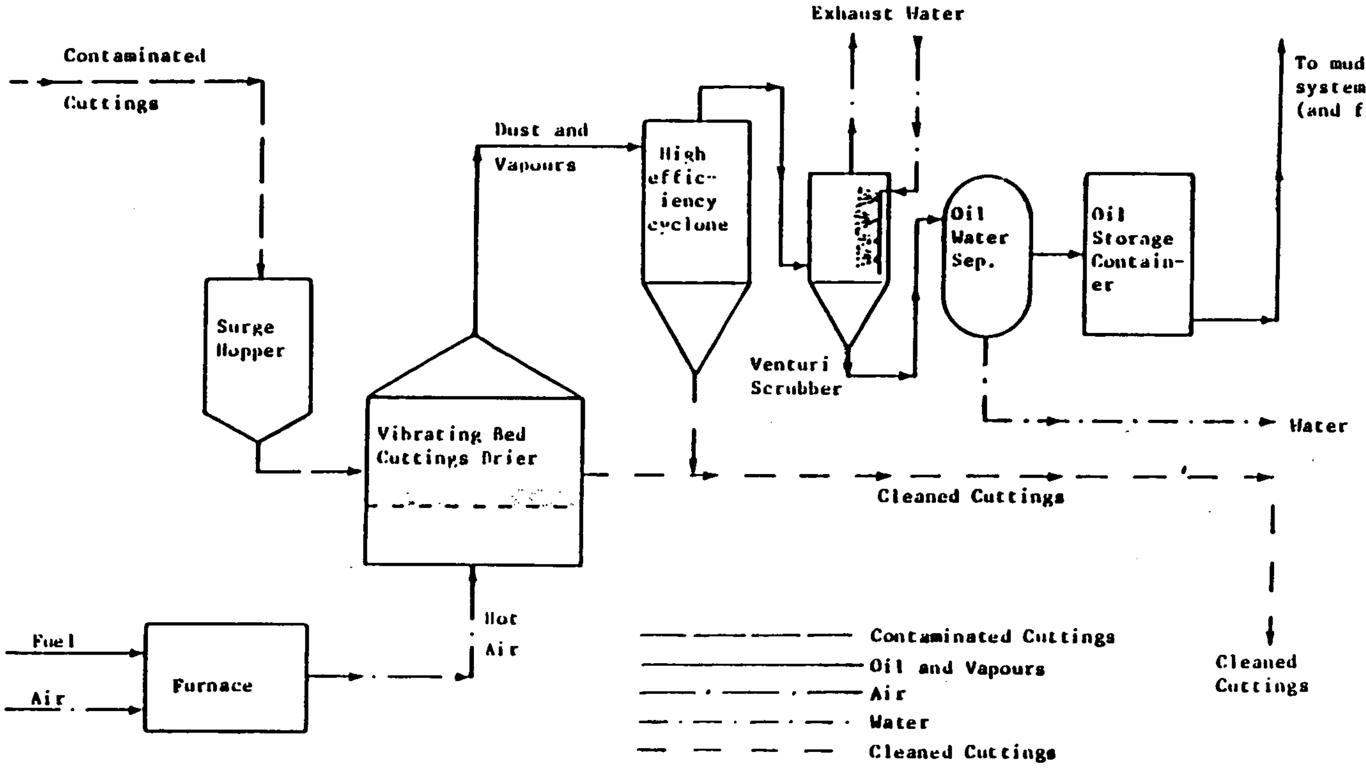
6. SPACE AND STORAGE

a. The proposed system would be mounted on 3 skids:

	(L x W x H) m
Furnace and air pump	4.5 x 2.1 x ?
Surge hopper, cuttings drier and control	7.0 x 3.0 x ?
Cyclone, scrubber, air pump, oil/water) separator and oil storage container)	11.5 x 2.7 x 9.1
The complete system would occupy	13.7 x 7.9 x 9.1 m

b. Hold up volumes of the surge tank and oil storage tank are not known.

c. Around 30 tonnes.



DRESSER SWACO VIBRATING BED CUTTINGS DRIER

Oiltools Cuttings Disposal System

Type: Thermal distillation, continuous process.

The CDS unit (Cuttings Disposal System) is a two-stage distillation process. Oily cuttings enter the top of the unit and are transported down a heat tube (at 760°C) by an internal auger. Some of the vapours distill off and are collected and ignited with air to heat the heat tube and auger. The partially cleaned cuttings travel down a second heat tube for final hydrocarbon recovery (these vapours are also recycled and ignited). The cuttings are cooled with seawater then discharged overboard from the bottom of the unit.

Answers to Questions.

1. CAPITAL COSTS

   Around $1.2 million or $1200/day rental.

   a. Claimed suitable for installation on either.

   b. Not sure - but performance should satisfy most regulations.

   c. Yes, as long as units are accessible.

   d. Used during drilling with oil-based muds.

   e. Not known.

2. MAINTENANCE COSTS

   Not known.

   a. Not known.

   b. Not known.

   c. Cuttings processor is relatively bulky, other items should be fairly easy.

   d. Each processor would have to be shut down completely for maintenance.

3. SYSTEM EFFICIENCY

   a. Full-scale testing of the unit showed residual oil on cuttings levels to be 0.6 g oil/100 g dry cuttings or less (analyzed by Freon Soxhlet extraction).

   b. No oil recovered (used to supply heat energy).

4. OPERATIONAL CONSIDERATIONS

a. The maximum throughput in physical terms is around 4.25 m^3/hour (around 8.5 tonnes/hour of oily feed). Actual capacity is limited by the burner rating of 3077 kW - this must combust all the oil on the cuttings. Hence, capacity depends mainly on the oil loading on the cuttings. At 25 wt % oil on cuttings, a capacity of around 1 tonne/hour is indicated.

b. Until proven system would require almost constant supervision.

c. Specially-trained engineer and operators would be required.

d. 1 man per shift.

e. Continuous process. Surge tank is supplied to act as a buffer.

f. Start up power (electric heaters) - 300 kW. Total operating power of 85 kW is divided as follows:

Auger drive motor	7.5 kW
Processor blower motor	15.0 kW
Screw conveyor (from solids control)	7.5 kW
Surge tank	18.0 kW
Cutting slurry pump	37.0 kW

5. SAFETY CONCERNS

a. In the event of an explosion or uncontrolled combustion, damage could result.

b. As above. It is not known whether combustion product fumes will present a problem. The outer shell temperature of the processor is 54°C.

c. Potential fire hazard. System must be attached to seawater and halon supplies. Halon is injected as an inert gas fire extinguisher and, as an extreme last resort, seawater can be injected to drench the system.

d. There is potential for incomplete combustion of the oil vapours.

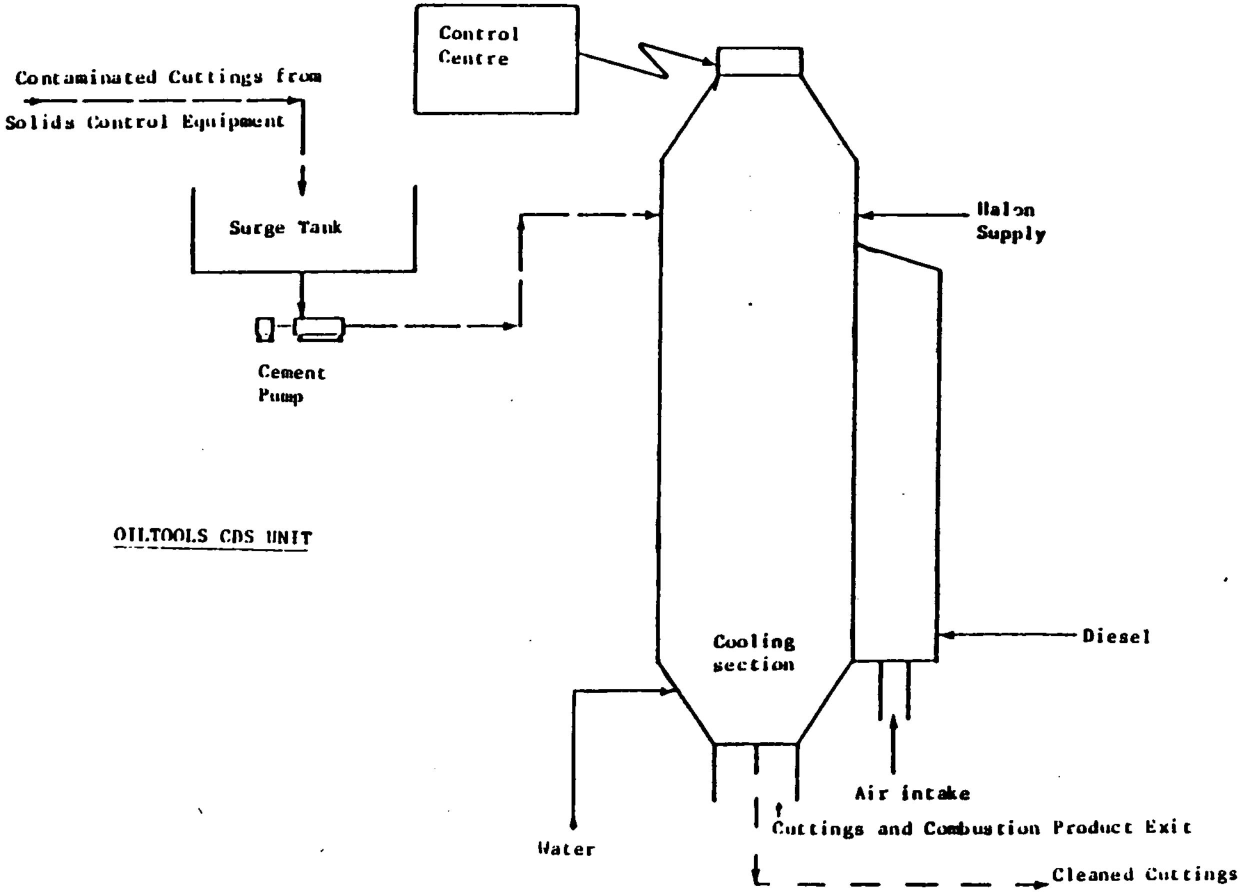
6. SPACE AND STORAGE

a. The system occupies the following:

	(L x W x H)
Cuttings processor (with control centre, sample platform and mounting yoke)	4.5 x 3.7 x 6.7
Surge tank	3.2 x 3.1 x 2.5
Slurry pump	1.9 x 0.7 x 1.0

b. The surge tank holds up to 24 m^3 (around 150 bbl) of cuttings.

c. 22 tonnes total.



OILTOOLS CDS UNIT

OILTOOLS CDS UNIT

Star Industries Volitilizer

Type: Thermal combustion, continuous system.

The Star Volitilizer is a 12 ft long tubular, ribbon type conveying system which is totally encapsulated in tubular explosion-proof heating elements. The tube with the heating elements is thoroughly wrapped in high grade insulation material. Above the insulation material is a sheath totally enclosing the cylinder.

The heating elements have the ability to reach temperatures as high as 1500°F (816°C) and are controlled via an explosion-proof panel.

The cylinder rotation is controlled by a variable speed drive allowing the system to vary its processing speed to keep up with drilling.

The entire system is skid mounted for easily handling.

Hamjern A/S Fluidized Bed Combustion System

Type: Thermal combustion, continuous system.

Cuttings are fed into the bed and oil is burned from them. Temperature control is affected by excess air cooling and immersed cooling tubes. Flue gases are cleaned in a cyclone. All solids may be discharged overboard.

Answers to Questions.

1. CAPITAL COSTS

   1000 Nkr/kW input energy. Hence Nkr 8 million for an 8 MW, 3 tonne/hour unit, chosen as an example.

   a. Size and weight constraints probably limit installation to a large fixed platform.

   b. Performance should satisfy most regulations.

   c. Unlikely due to size and weight of unit.

   d. Used during drilling with oil-based muds.

   e. Not known.

2. MAINTENANCE COSTS

   Not known.

   a. Not known.

   b. Not known.

   c. Bulky - although moving parts such as pumps, etc., should be relatively easy to handle.

   d. Unit would have to be shut down completely for maintenance.

3. SYSTEM EFFICIENCY

   a. No quantitative data. However, tests were carried out in a 2 MW pilot plant and the treated cuttings (and recovered fines) viewed by the Institute of Offshore Engineering were dry and had little or no residual hydrocarbon odour.

   b. No oil recovered (combusted in bed).

4. OPERATIONAL CONSIDERATIONS

a. Systems available to process feeds of heat content between 2 and 20 MW. This equates to 0.7 to 7.7 tonnes per hour of feed containing 25 wt % oil. Systems self-regulate if feed has calorific value between 8000 and 40,000 kJ/kg.

b. Until proven offshore, system would require almost constant supervision. The system is claimed to be fully automatic.

c. Specially-trained engineer would be required.

d. Hamjern claims the process could operate without personnel. However, it is likely that at least 1 specially trained operator would be required on board.

e. Continuous process. No surge facilities supplied by manufacturer - this may prove necessary.

f. Around 2% of the feed input energy - hence 160 kW for an 8 MW unit. Start up (takes less than 1 hour) also consumes around 1.5 bbl diesel fuel.

5. SAFETY CONCERNS

a. In the event of an explosion or fire, damage could result.

b. As above. Unit outer skin temperature is 60°C maximum. Cuttings would discharge from unit at elevated temperatures - it is not know whether fumes will present a problem.

c. Potential fire hazard - e.g., if cuttings were discharged before completely combusted or if a slug of oil mud entered the bed.

d. Potential for incomplete combustion and for contamination by fines.

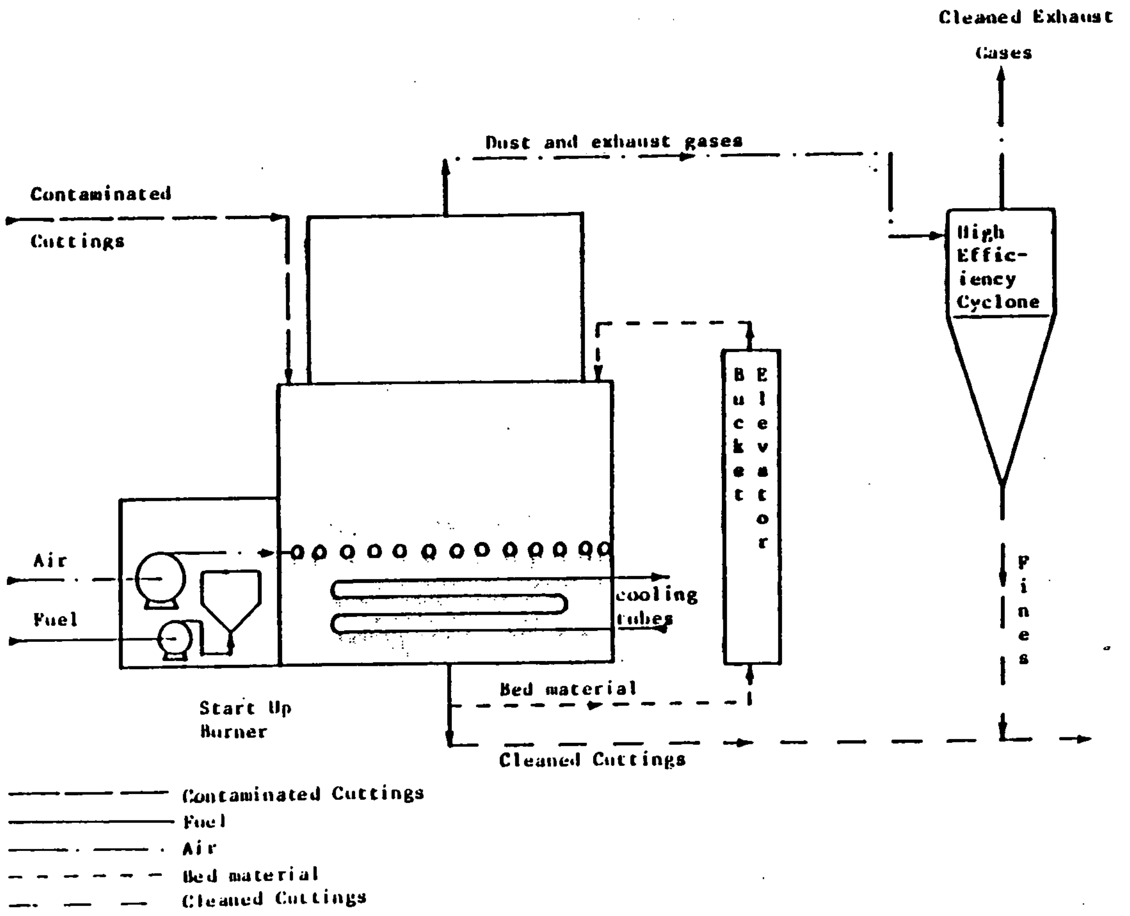
6. SPACE AND STORAGE

a. 7 x 5 x 7 m (L x W x H) for an 8 MW combustor plus 7 x 5 x 7 m (L x W x H) for fines separation cyclone and flue gas cooler.

b. Surge facility size (if any) would depend on operator requirements.

c. Around 50 tonnes.

HAMJERN MB FLUIDISED BED SYSTEM



West's Engineering Design Ltd. Fluotherm Fluidized Bed Combustor

Also been called West's Prochem/Walsh Prochem

Type: Thermal combustion system, continuous process.

Reference 21.

Cuttings are fed into the bed and oil is burned from them. Temperature control is effected by excess air cooling or diesel injection heating. Flue gases are cleaned in a baffle/quench chamber for cyclones. All solids may be discharged overboard.

This system was seriously considered for installation on a large UK Sector North Sea platform (but was not, in the end, chosen).

Answers to Questions.

For general points, see information on Hamjern system.

1. CAPITAL COSTS

   Two systems have been proposed - 5 and 10 tonnes/hour - the latter is virtually 2 of the former in parallel.

   $ 650,000 for 5 t.p.h. unit.
   $1,050,000 for 10 t.p.h. unit.

   a to e. See Hamjern.

2. MAINTENANCE COSTS

   a to d. See Hamjern.

3. SYSTEM EFFICIENCY

   a. Tests on a 0.3 m dia. pilot plant showed reduction of oil on cuttings from 13-16 wt % in feed to 0.08 wt % (method of analysis not known).

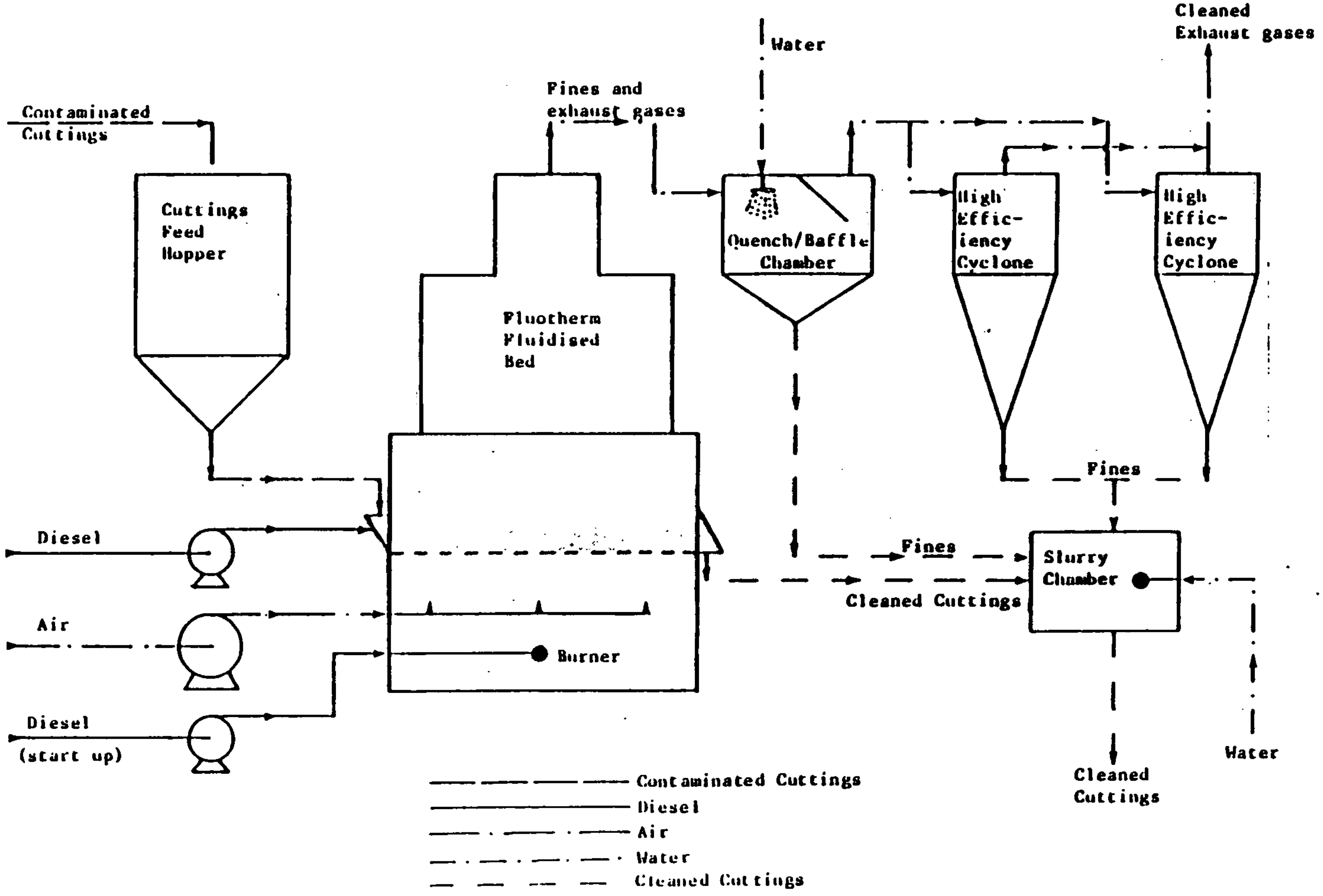
   b. No oil recovered (combusted in bed).

4. OPERATIONAL CONSIDERATIONS

   a. 5 or 10 t.p.h. units available, designed for a feed containing 20 wt % oil maximum.

   b. Until proven offshore, system would require constant supervision.

   c. Specially-trained engineer and operators would be required.



WEST'S PROCHEM FLUOTHERM FLUIDISED BED COMBUSTER

Buchen and Leo GMBH LECO Quicklime Stabilization System

Type: Stabilization System

Oily cuttings are stored in a hopper, then passed to a two-stage mixing/reaction unit where CaO is added. The mixture is then slowly conveyed to the discharge point during which time the CaO reacts with the water on the cuttings to form a dry, solid powder.

Where relevant, data are included for this sytem as a comparison between onshore and offshore treatment systems.

1. CAPITAL COSTS

   Processing costs are DM 110/m^3 feed - purchase cost is unknown.

   a. N/A.

   b. System is designed to produce a product suitable for use as a subgrade for road construction or similar.

   c. System is designed for easy transportation from site to site.

   d. Used to treat shipments of oily cuttings.

   e. Not known.

2. MAINTENANCE COSTS

   Not known, but if unit is rented or if cuttings are processed on a charge per tonne basis, maintenance costs should be met by the owner.

   a. Not known.

   b. Not known.

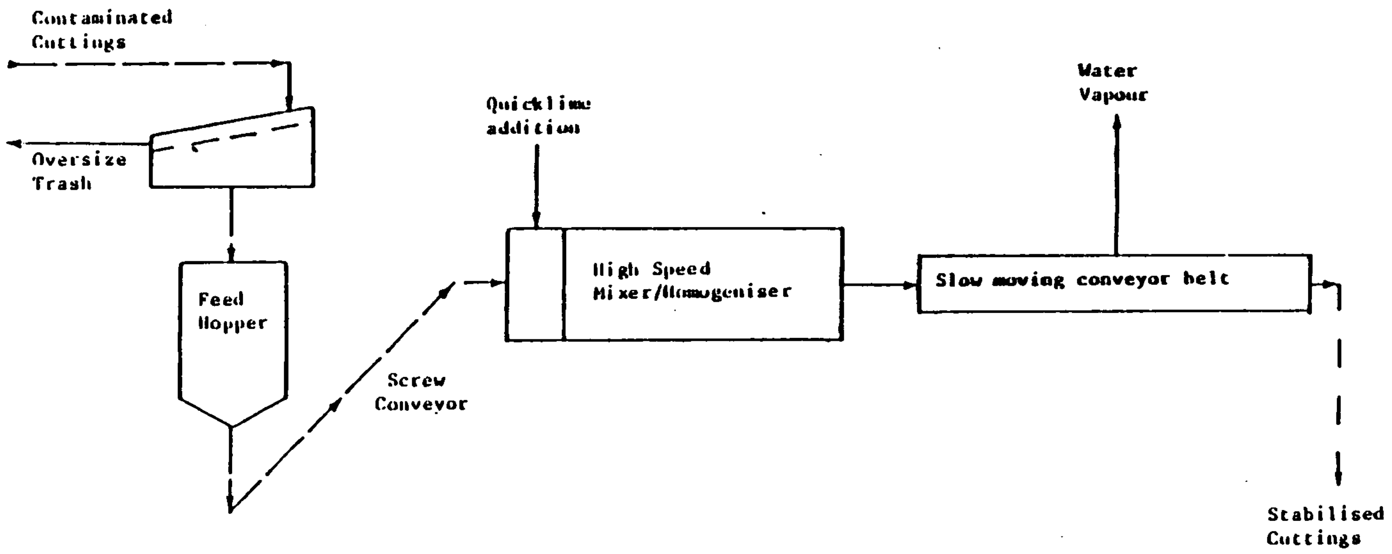
   c. Should be relatively easy.

   d. None - not so important onshore.

3. SYSTEM EFFICIENCY

   a. Process is claimed to produce a stabilized product of low permeability to water - 10-9 to 10-7 - which implies that leaching rates of oil from the final product should be slow.

   b. No oil recovered (stabilized on the cuttings).



BUCHEN AND LEO LECO QUICKLIME STABILISATION SYSTEM

Other Quicklime Stabilization Processes

Considerable large-scale experience is already available on the stabilization of oil-contaminated beach sands using standard grades of industrial quicklime rather than the specially-treated quicklime proposed by Buchen and Leo. This work was carried out in France following large scale spills from the Amoco Cadiz and Tanio incidents. A review of the work plus and account of smaller scale studies on particular aspects of quicklime stabilization is given in Reference 25. It is stated in the report that there is no apparent advantage to using modified quicklimes over using a standard grade (the modified limes are more expensive, and standard grades react more rapidly and give statisfactory leaching results).

Mobil Oil Corporation Briquetting System

Type: Stabilization

This system would have operated by stabilizing the oil on cuttings rather than removing it. Considerable development work was carried out before the project was terminated.

Cuttings are crushed then mixed with an oil absorbent binder. The stabilizing mixture is then compressed into briquettes prior to discharge overboard.

Answers to Questions.

1. CAPITAL COSTS

   Not known.

2. MAINTENANCE COSTS

   Not known.

3. CAPACITY

   40 tonnes/hour

4. CLEANING PERFORMANCE

   Not applicable

5. WEIGHT

   Not known.

6. SIZE REQUIREMENTS

   Not known.

7. POWER REQUIREMENTS

   1,750 kW (this figure was to cover all mud processing area requirements)

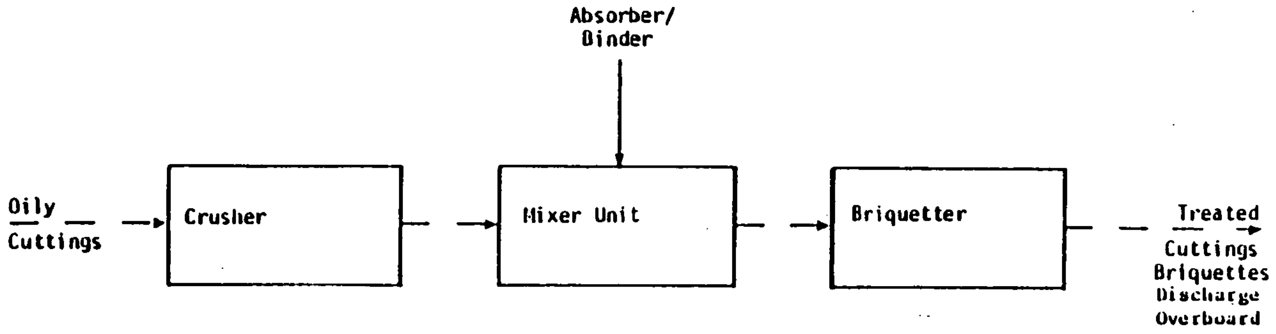
8. CHEMICAL REQUIREMENTS

   Not known

9. OPERATOR REQUIREMENTS

   Not known

Note that is was intended to install 2 trains of systems on the Statfjord platforms, as part of a solids control/cuttings treatment package (mud processing area).



MOBIL OIL CORP STABILISATION/BRIQUETTING SYSTEM

Thule Ultrasonics Assisted Wash System

Type: Other - Immersion wash with ultrasonics.

In this proposed system, cuttings would be washed in aqueous detergent solution then pumped through an ultrasonic vibration unit to a settling tank. Released oil should rise to the surface from where it can be skimmed for further treatment and possible return to the active mud system. The solids and water would be discharged overboard.

Answers to Questions.

1. COSTS

   Not known.

2. CAPACITY

   Designed to treat cuttings generated in 17-1/2" hole.

3. CLEANING PERFORMANCE

   Not known.

4. WEIGHT

   Not known.

5. SIZE REQUIREMENTS

   Not known.

6. POWER REQUIREMENTS

   Around 50 kW ultrasonic power.

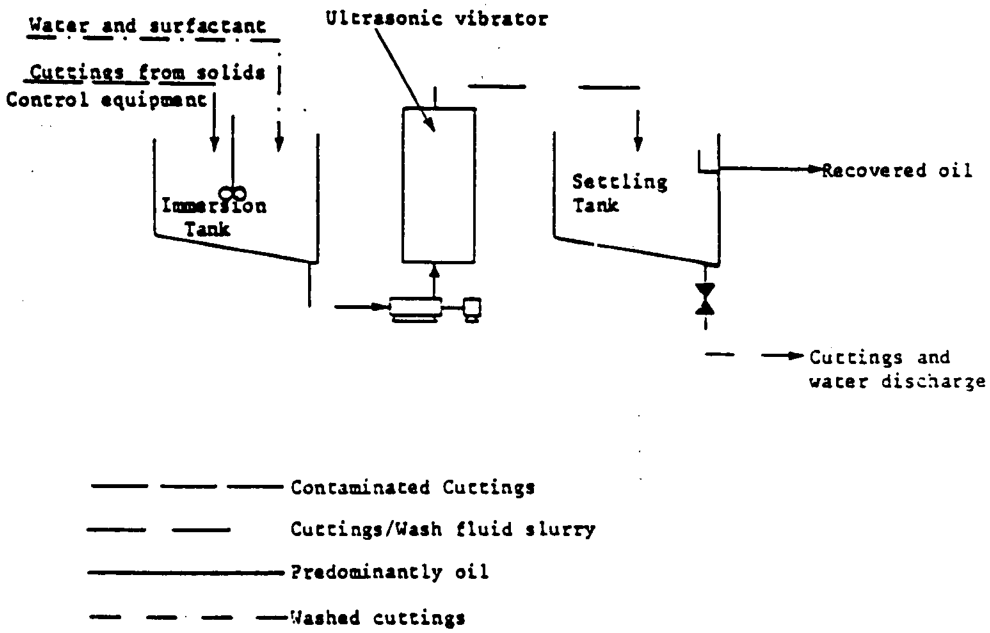
7. CHEMICAL REQUIREMENTS

   Not known.

8. OPERATOR REQUIREMENTS

   Probably 1 per shift.

(SIMPLIFIED) THULE ULTRASONIC WASH SYSTEM



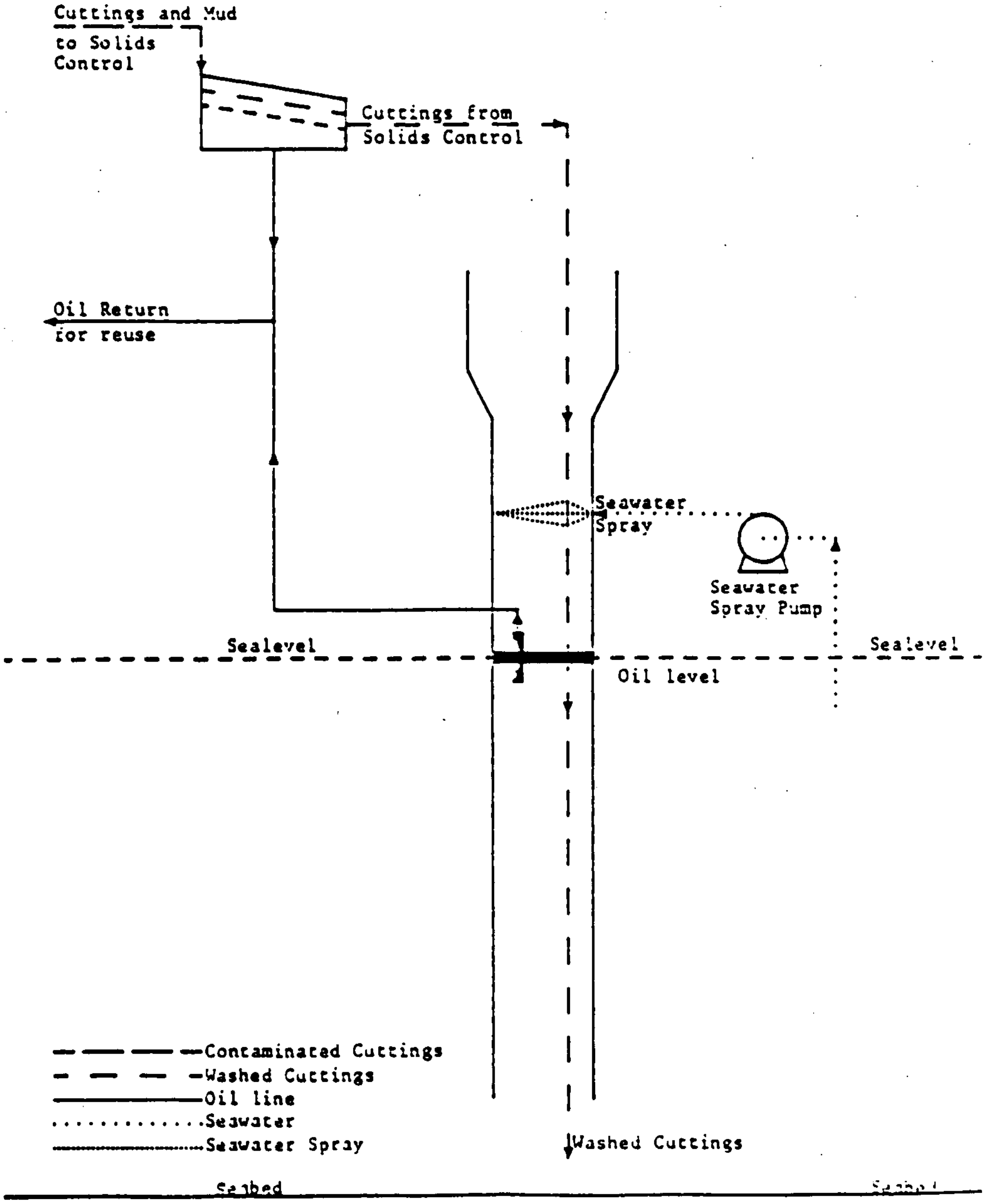
Chromalloy Delta Mud Sluiceway System

Type: Spray wash with seawater.

This simple system has been developed and tested by a drilling fluids company in the USA. Only limited data are available.

Cuttings are sluiced with seawater from the solids control equipment to a casing which extends 15 to 75 metres below the sea surface. As cuttings fall to sea level, they are sprayed with seawater jets. Any oil released should form a layer on the surface and can be recovered by a skimmer pump. It is claimed that the recovered oil may be recycled the active mud system. The cuttings will, meanwhile, fall to the seabed.

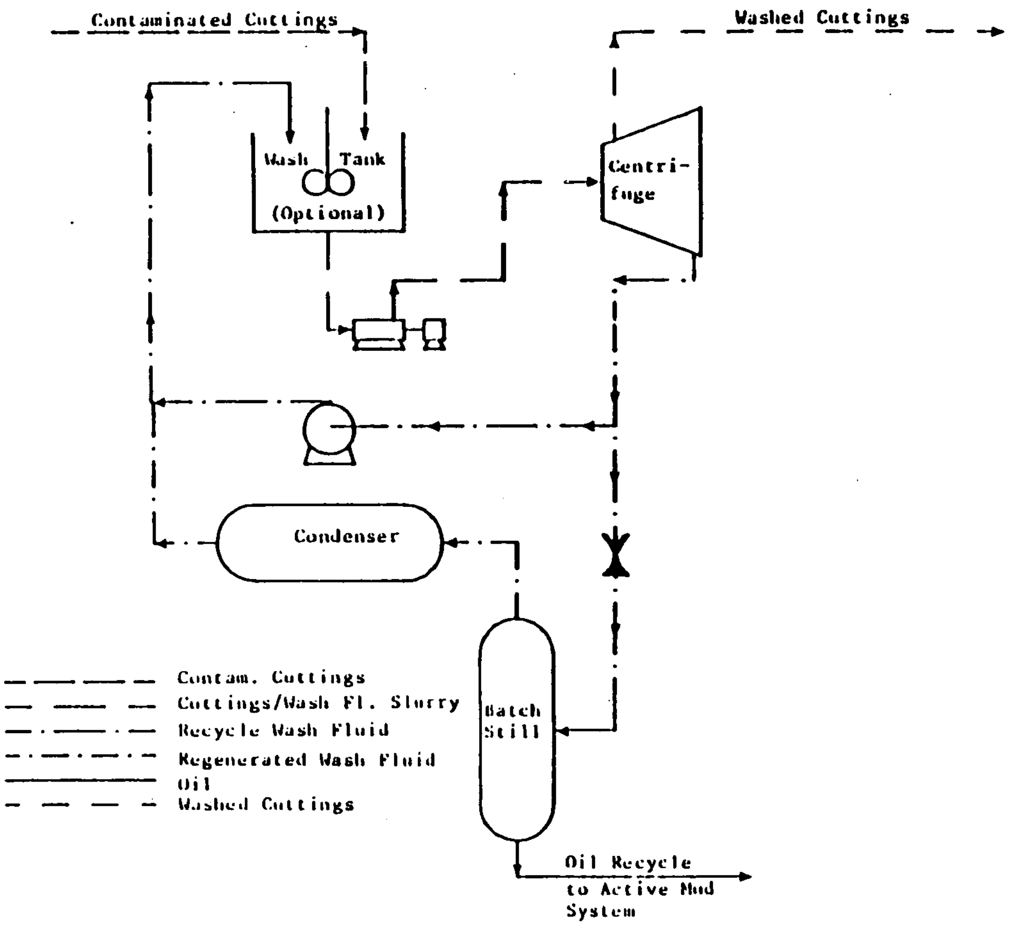
CHROMALLOY DELTA MUD SLUICEWAY SYSTEM



Mudtools/FIS Trichloroethane Centrifuge Wash System

This system is a simplification of the process described for Sweco/FIS Trichloroethane. The complete system has not yet been tested.

Cuttings would either be sluiced directly to a 2-phase decanting centrifuge or optionally washed in an agitated tank first. The centrifuge yields recycle trichloroethane wash fluid and treated cuttings (for discharge overboard). Fines and oil would be removed from the solvent by a batch still (and recycled to the active mud system).



MUDTOOLS/FIS TRICHLOROETHANE CENTRIFUGE WASH SYSTEM

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