UKOOA Drill Cuttings Initiative

Final Report

of the

Scientific Review Group

January 2002

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- The Scientific Review Group functioned as an independent scientific and technical accreditation and advisory group for the research programme.
- The Scientific Review Group reported to the Executive Committee of the Initiative.

1. Membership of the Scientific Review Group

Chairman: Professor John Shepherd, MA, PhD, CMath, FIMA, FRS

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2. The Remit of the Scientific Review Group

- Provide comment and advice on scientific and technical aspects of the R & D programme
- Undertake peer review of both R & D proposals submitted and reports received of work undertaken under the programme, calling in additional expert advice if necessary
- Assist in the synthesis and interpretation of the findings of the programme, for the Steering Committee and other stake-holders
- Contribute to the dialogue process and the communication of the results to stake-holders
- Comment freely on any aspects of the programme as and when the Group considers this to be necessary and desirable
- Advise on, and contribute to, the publication of the results of the programme

3. Overall Evaluation & Recommendations

The Scientific Review Group confirms that

- it has read and reviewed all the reports of the scientific research programme and interacted with research contractors involved when this was necessary
- the contractors and authors have responded positively to the comments and criticisms made by the Scientific Review Group
- additional information requested by the Scientific Review Group was made readily available
- the final reports of the programme are, so far as we are aware, free of serious errors, omissions or mis-representations.

> ***Note***: *the Scientific Review Group provides peer review of the quality of the scientific work carried out. The final responsibility for the contents of the reports however, rests with their authors and the Executive Committee of the UKOOA Initiative, and it should not be assumed that the Scientific Review Group would necessarily support or endorse each and every statement in the project reports.*

The Scientific Review Group considers that the scope and quality of the research undertaken during the two phases of the programme was satisfactory overall, and adequate to support the general conclusions drawn concerning the relative merits of the various options considered. In particular we support the conclusion that the most suitable options are removal, covering, and leaving in place to allow natural degradation, and that the balance of advantage between these will depend on the specific characteristics and the environment of individual cuttings piles. Where removal is a preferred option, re-injection of material recovered appears to be both technically and environmentally superior to disposal elsewhere.

However, the compressed timescale for the research programme, and the limitations on the funding available, meant that those aspects requiring long-term studies, and/or in situ observations in the field, could not be undertaken to the extent which we regard as desirable. For this reason, among others, the results of the research carried out under the UKOOA Initiative will not be sufficient on their own to enable firm conclusions to be drawn about the best environmental strategy for the treatment of specific cuttings piles, when this becomes necessary. The additional work which will be required will include :

- Detailed characterisation of the piles, by means of periodic volumetric surveys, extensive full-depth coring, and mineralogical and chemical analysis
- Measurements of geo-technical properties including shear strength, erodability, and porosity
- Characterisation of the local physical and biological environment (wave forced and tidal currents, sedimentary environment, benthos)
- Improvements to the model, and further work on the validation of its results
- More emphasis on quantification of the environmental impacts of contaminants

In addition, we recommend that the planned continuation of Task 3, to generate a time-series of observations of relevant processes (biodegradation, recolonisation, bioturbation, surface loss) in the field be implemented, in order to provide more reliable estimates of the crucial parameters which will be required for the modelling studies of specific piles. The Scientific Review Group also recognises that the Long Term Fate Model has had to be generated on the basis of an insufficient database. Further field work and surveys will also be required to enable the validation of future modelling results.

Detailed comments on the final reports for the various Tasks are given in Annex 1. Much of the Scientific Review Group's work was carried out individually, and/or by e-mail. A number of meetings were also held to enable consolidated views to be formed and a list of these meetings is given in Annex 2..

Professor J.G. Shepherd FRS (Chair of Scientific Review Group); 18 January 2002

TASK 1; OFFSHORE SURVEY FOR SAMPLE COLLECTION: CHARACTERISATION OF CUTTINGS PILES: BERYL AND EKOFISK (PARTS 1 AND 2)

The report reviews, and depicts in graphical form, the characteristics of a range of cuttings piles, establishing their extreme heterogeneity. It covers the physical parameters, organic contaminants and metal contents (Al, V, Mn. Fe, Ba, Cr, Co, Ni, Zn,Sr, Cd, Pb and Hg). Total organic carbon (TOC), total organic nitrogen (TON), pH, redox potential (Eh), and sulphide concentrations are considered. Benthos, endocrine disruptors and naturally occurring radioactive material (NORM) are also dealt with to some extent.

There is a much greater degree of bedding in some cuttings piles than in others but this is not fully addressed. The report does bring out the fact that Ekofisk is not a truly water-based mud (WBM) pile. It is useful to have the XRD and XRF data included in the final version of the report.

There is still limited data on critical information, such as the slopes of piles (estimated at a maximum of 35 degrees for the highest piles of around 19 m, but with limited zones with slopes as steep as 60 degrees being guessed at). Piles need to be thoroughly cored, especially through their thickest parts and into the former sea floor.

The very high proportion of fine-grained components was emphasised, as was the severe limitation of core data.

More data are required before generally applicable statements can be made with confidence. The compactional data produced by a subcontractor are both good and useful. These data provide *prime facie* evidence that oil in particular, and other components in general, are most likely to be retained within the body of a drill cuttings pile. Significant release, e.g. of oil and heavy metals, is most likely to take place as a result of erosion at the surface of piles (i.e. the sediment/water interface). The metal speciation study (presented in Part 2 of the report), partially based on sequential extraction of a range of cuttings samples, is comprehensive and gives a good overview of the metal contents, speciation and mobility in cuttings piles material. There is a consensus that cuttings piles metals are not generally bioavailable. However, it is important to underline the statement that metal sulphides may become available to biota if the environment turns oxic. In fact the oxidation of sulphides to more accessible forms may be a rapid process. The report advocates caution in linking chemical extractability to bioavailability, which we endorse. One aspect of bioavailability which should have been addressed is the adsorption in the gut of sediment feeders, where the impact of digestive fluids may change metal partitioning and availability. The study has only treated filter feeders where uptake from the dissolved state across gills seems the major route of accumulation.

Compaction, erosion and deposition (re-deposition) are likely to be important processes affecting piles, so in future the characterisation of the erodability of pile materials will be required and should be established as part of the necessary protocol.

It is suggested that protocols should be established to evaluate all piles requiring action (including those that are to be disturbed as part of a platform removal operation). Data need to be gathered from cores taken through the total depth of the pile (into the former sea floor and in the thickest part of the pile). Data should be collected from these cores covering the spectrum of parameters embraced in this report (grain size, sorting, mineralogy, bulk elemental geochemistry etc), and it is recommended that these data are displayed as core logs for each core (for potential correlation across the pile) so that the heterogeneity of the pile can be fully appreciated. Such an approach will increase confidence in the decision-making process (whether to leave in place, to lift or other options). Samples should be taken at closely spaced intervals within such cores. If possible, the cores should be taken in such a way that minimum disturbance of cuttings pile material is achieved (such coring techniques are available). The bioavailability of heavy metals (and other substances) should also be evaluated (i.e. speciation in the context of bioavailability).

TASK 1; OFFSHORE SURVEY FOR SAMPLE COLLECTION: ENDOCRINE DISRUPTION FROM DRILL CUTTINGS MATERIAL (PART 3)

The report on Part 3 of Task 1 is well written and covers all aspects of endocrine disrupting substances (EDS) in general. This includes aspects that seem less relevant for possible EDS in drill cuttings because of differences in toxicity mechanisms (like tributyl tin, TBT).

The report covers the *in vitro* tests on EDS, namely a yeast-based assay for estrogens (YES) and androgens (YAS) and a cell-line-based assay for estrogens (ER-CALUX), androgens (A-CALUX) and dioxins (DR-CALUX).

Some of the methodological limitations of the study have been insufficiently emphasised. These include the effects of the extraction procedure, the high cytotoxicity found in the extracts and the difficulty in extrapolating the *in vitro* results to the *in vivo* situation (e.g. presence or absence of metabolism and differences in bioavailability of the putative EDS). More attention could have been given to the interpretation of the experimental findings (i.e. weak effects in non-cytotoxic tests; confounding effect of non-lethal remaining cytotoxicity; similar effects in reference sediment).

Because of these findings, the wording of the discussion, (to a lesser extent) the conclusions, and the summary should have been even more careful than it already is. Since EDS are presently of high societal concern, it is important to put any positive findings into perspective by discussing their biological relevance. Only then will it be possible to decide whether additional studies are necessary and, if so, how these should be executed. Based on the material analysed in this study, the low contents of EDS in drill cuttings are unlikely to be a major cause for concern.

General comment on analysis of organic matter in cuttings piles

The reports prepared during Phase II of the UKOOA Drill Cuttings Initiative revealed that applying some of the available rapid screening techniques for the analysis of organic matter in drill cuttings and related materials (during determination of cuttings pile inventories, in the course of laboratory experiments and during environmental monitoring) did not yield satisfactory results in all cases. It is therefore suggested that for the analysis of drill cuttings material (in the widest sense) the following points should be considered:

- Determination of total organic matter by measuring the loss on ignition (LOI) only allows a black-and-white picture in the sense that highly oil-bearing cuttings will give high LOI values. Absolute numbers are strongly affected, however, by other effects of thermal loss, like release of bound water from minerals or decomposition of labile minerals (carbonates, sulphides). Total organic carbon (TOC) determination by combustion, if accurately performed, should yield data that will be more representative of the total organic matter content; this may be complemented by thermal desorption/FID measurements in cases where there are indications of the presence of a high amount of highly volatile organic material.

- Fluorescence analysis is linked to the presence of fluorescing moieties in petroleum-type material, usually aromatic nuclei. Source rock bitumen and natural petroleum are rich in these substances, and calibrating the method with a related natural crude oil provides a proper basis for valid analysis of these materials. However, although drilling fluids will contain fluorescing substances when diesel oil was applied, the refinery process may have altered the ratio of fluorescing to non-fluorescing constituents to the extent that calibration with a natural crude oil will be a source of analytical error. Calibration with a typical diesel product is recommended in these instances. Fluorescence analysis will typically fail when low-toxicity, synthetic oil was used as drilling fluid due to the lack (or low concentration) of fluorescing substances.

- The detection of a significant level of polychlorinated biphenyls (PCBs) in Ekofisk drill cuttings was unexpected. The analytical protocol for drill cuttings pile inventories should allow for the possibility of other “surprises”. Thus, gas chromatography-mass spectrometry (GC-MS) analysis should not only be used for screening for known, expected compounds. Rather there should be time and funding sufficient for additional structural assessment of unknown compounds, showing up as significant components in the GC-MS traces. Furthermore, the possibility of using LC-MS analysis in addition (to screen for compounds too involatile to be detected by GC-MS analysis) should be considered. A suitable screening technique for the presence of significant amounts of low-volatile organic compounds is to determine the ratio of material injected onto the GC column and the fraction reaching the detector by the use of a calibration standard.

It should be stressed again, that a suitable coring technique must be used for sampling through the centre of a cuttings pile down to the underlying sediment in order to obtain representative samples of the oldest pile material and the underlying sea floor.

TASK 2A; TOXICOKINETICS OF WATER BASED MUD DRILL CUTTINGS CONTAMINANTS IN MARINE SEDIMENT

The scope of the work undertaken was somewhat reduced compared to what was originally planned in the Phase II programme, and does not cover the chronic toxicity aspect of the toxicokinetics. The performance of the *Corophium* and *Sceletonema* tests seems reliable, but the Scientific Review Group questions certain procedural details of the chemical analyses conducted. It is unfortunate that the conclusions from the range-finding tests could not be followed up in the revised *Corophium* tests due to lack of test material. Testing for 100% water-based mud (WBM) material would be highly relevant, both since the LC50 level was not reached at lower concentrations and exposure to pure WBM cuttings is a realistic field situation. It is also unfortunate that the reference sediment contributed significantly to the hydrocarbon regime of the tests. The observation that WBM exerted less mortality to *Corophium* than oil-based mud (OBM) cuttings at equal hydrocarbon exposure is interesting and confirms that the types of hydrocarbons involved are important.

TASK 2B; ASSESSMENT OF THE ACTUAL ENVIRONMENTAL IMPACTS OF REPRESENTATIVE OIL BASED MUD AND WATER BASED MUD CUTTINGS PILES

This is a well-executed study and the report is clear and well written. It provides much useful information on the present state of the North Sea and is effective in establishing the context and comparative scale of the contaminants associated with cuttings piles. There is considerable emphasis on the physical disturbances to the habitat of organisms, which are considered in the context of other disturbances. This has also been done for contaminant inputs, for which a more quantitative approach has been possible. Although the results still suffer from the lack of hard data and a large number of estimations and approximations were inevitably required, there has been substantial progress relative to the Phase 1 report. The shortcomings are well documented in the report.

The results indicate that the present effects of existing piles are highly localised, and the spatial extent of the areas affected is a small percentage of the total. The total quantities of hydrocarbons in the piles are substantial (about 150,000 tonnes), but these are largely immobilised and are only being removed very slowly by erosion, degradation and leaching (over several or many decades). The rate of release to the wider environment is therefore small in relation to the amount of hydrocarbons from other sources (e.g. rivers).

TASK 2C; WATER COLUMN AND FOOD CHAIN EFFECTS (OIL BASED MUD)

The prime objective was to investigate the exchange of contaminants from water-based mud (WBM) and oil-based-mud (OBM) cuttings to the water phase and, through uptake studies with animal species representing a two-step food chain, to investigate both the bioavailability and potential food chain transfer of the cuttings piles contaminants. This was done through a set of mesocosm studies.

The study only met the objectives to a modest degree, one of the main reasons being constraints on the experimental design and lack of replication, which rendered statistical treatment of the results impossible or at least very dubious. This limitation is clearly seen in the attempts to analyse changes in sediment concentration of contaminants in the course of the experiment, where large spatial variability and few or no replicates made it very difficult to detect real changes. In fact, an increase in sediment contamination over time was more frequently found than a decrease. Also the study of changes in tissue contamination in the organisms suffered from lack of replicate experiments and hence gave very low resolution. It is also surprising that total hydrocarbons (THC) were not included in the analytical programme, especially since THC was the focus of the entire project.

Another obstacle to reaching the objectives (which could have been avoided to some extent through better design) was the fact that the model organism selected to study sediment-organism transfer of contaminants, the lug-worm *Arenicola marina*, suffered from more than 90% mortality and hence could not be sampled for tissue analysis. The rag-worm *Nereis diversicolor*, which was added as prey for the turbot *Scopthalmus rhombus* in the two-step food chain experiment, seemed inappropriate both because it appeared that the turbot preferred the lug-worm, and because the rag-worm was introduced without any preconditioning to the test sediments. In summary, no information exists on the levels of contaminants in the preferred prey for the turbot. Also the design did not allow any distinction between food uptake and uptake from direct contact with the test sediments by the turbot.

It is therefore doubtful if the chosen design, even with satisfactory statistical resolution, would have given reliable information on the food chain transfer of cuttings piles contaminants. Further longer term and/or *in-situ* experiments will be required to resolve the matters satisfactorily. However, the indications of the work undertaken, which was not surprising, are that hydrocarbons tend to be assimilated by but not accumulated in the organisms.

TASK 3; INITIATE COMPARATIVE TIME SERIES DATA ON FACTORS DETERMINING FUTURE PILE VOLUME FROM REPRESENTATIVE OIL BASED MUD & WATER BASED MUD CUTTINGS PILES

JOINT REPORT

The objective of Task 3 was to begin generating time series data on factors that affect the cuttings piles. These data were intended to be used in Task 4, which involves the development of a mathematical model to predict the physical, chemical and biological changes in cuttings piles over time.

The work in Task 3 was divided into six principal research activities, namely:

- erosion processes using a large scale experiment;
- depletion of contaminants in drill cuttings mesocosms;
- aerobic and anaerobic degradation in small scale laboratory experiments;
- recolonisation in small scale laboratory experiments;
- bioturbation in small scale laboratory experiments
- chemical biomarker development.

Separate studies were carried out for each of the above tasks and individual reports prepared. The Scientific Review Group has considered each of these reports and its comments are presented below.

The Joint Report firstly summarises the work undertaken and the principal findings that have emerged from the individual activities. Secondly, it attempts to draw out numerical parameters for use in the Task 4 Model from the experimental results.

Many of the experiments were carried out without replication and on cuttings material that had been disturbed to varying degrees. The cuttings material also appeared to be highly heterogeneous. Where reference sediments were used these were not clearly categorised. In the animal experiments there was a high level of mortality after shipment, suggesting that the animals were highly stressed. Procedures in the bioturbation experiment were so questionable as to yield irrelevant data. The results from Task 3 experiments have therefore to be treated with the utmost caution and it is difficult to reach any firm conclusions in terms of rates of erosion, degradation or colonisation that may be used in the modelling work. Only broad trends emerged. The Scientific Review Group found some elements of this research and the associated reports to be unsatisfactory.

The Joint Report in its final discussion sections presents good qualitative descriptions of the processes that are likely to affect the cuttings piles over time. The report recognises the difficulties in determining quantifiable rate processes from the experimental work. However, its overall conclusion is that the dominant process is likely to be erosion with some biological degradation of total hydrocarbons (THC) in the top few centimetres of the surface active layer. These biological processes are considered to be of secondary importance to that of erosion. Although the Scientific Review Group considered the erosion experiments to have been well performed, it recognised that an active biological or physical crust on the cuttings pile surface could be important in modifying erosion rates but this factor has not yet been explored adequately. Furthermore, the wet density of the samples was quite low, but the density and the shearing resistance is likely to increase with depth. This may possibly lower the erosion rate but this effect was not considered. An attempt was made to draw out the principal results of the depletion, recolonisation and bioturbation data for use in Task 4 modelling. The text describing the tabulated data spells out the considerable uncertainties associated with the numerical values provided. However, there is no reference in the table to these. This is unfortunate as the tabulated values may be considered separately and used out of context.

It is patently clear that all of the results obtained from Task 3 must be treated by the modellers with caution. It is therefore particularly important for the models to be run with a range of parameters so as to test model sensitivity and possibly present upper and lower boundary solutions for each pile studied.

TASK 3-1; LARGE SCALE EXPERIMENT

The aims of the experiment were

- to define essential factors used as numerical model input data and to define data sets to be handled by the model;
- to define the erosion rate of the surface layers;
- to establish threshold level of shear stress for incipient motion;
- to establish the fate of the material removed by erosion
- to establish whether there is a stage at which no further erosion may occur and the size of the cuttings pile at this stage

The report is a clearly written document on a transparent and well performed project. Not all of the stated aims have been achieved, particularly the last two in the above listing. It is not made clear how the results derived in this experiment might be directly applied to the stated problem. There appears to be a mis-match between the considerable effort involved in constructing the experimental system and the relatively modest scope of the experiments themselves (only five experiments, each of about 4 hours duration). There is much scope here for considerably more experimentation, particularly beyond the four hours in each case, to define the point at which no more erosion occurs, for example. It is worth noting that a storm in the North Sea usually lasts considerably longer than four hours.

In the Beryl-specific entrainment/erosion experiments, where there were “crusts” colonised by anemones, the animals were removed first. This cannot be realistic. In the real world they would be there anchoring the sediment. Comments made with regard to re-erosion of “crusted” materials (a noted change of only 10% – 1.08 N/m^2 versus 0.97 N/m^2 – depending on whether a crust is present or not) should carry a clearly stated caveat. We accept that the results here do carry a word of caution in the report. The general applicability of the data is not clearly stated.

For the Ekofisk trials a comparison between the erosion behaviour of an active surface layer (ASL) and that of the same sample with the ASL removed would have been more interesting than comparing with the crusted surface, as done here. Such an approach would have been more in line with Questions 2 and 3 asked in the UKOOA scope for the task.

The distinction between resuspension and bedload transport is important for the further destiny of the eroded material, and the finding of dominant bedload transport (90% for Beryl, but no information for Ekofisk) is interesting and potentially significant.

The diagnosis that a combination of 100 year current speed and 10 year significant wave height, providing a shear stress of 12 N/m^2, and that erosion rates are 40 to 100 times greater at Beryl than at Ekofisk could be very significant. It is not clear why this particular combination of factors had been considered. In particular the 10 year wave height was questioned as being possibly too small. Very extreme events have not been examined, and these are the ones most likely to lead to erosion on the sea floor. If the limitations to these factors were due to limitations in the equipment, then this should have been more clearly stated. If there is some other reason, then these should have been stated too. The finding that a wave height of 10 m and wave period of 11 s will produce a near-bed orbital velocity amplitude of 50 cm/s at Ekofisk seemed to be both good and applicable data, but more interpretative weight could have been given to the data generated in terms of their general applicability. How realistic is the material used in the experiments by comparison with the *in situ* materials on the sea bed? On the sea floor there are often organic (bacterial) films (see Task 6 video) and these could increase threshold shear stresses significantly.

The fact that Ekofisk was found to have cement grout over parts of its surface made the Scientific Review Group wonder how many other “surprises” await detailed investigation of piles (i.e. how common are these, and as yet unknown, phenomena?).

More data are required on changes in shear strength once the covering biologically modified surface layer has been breached. There is also a need for more *in-situ* measurement. In terms of current speeds and other parameters, factors such as Reynolds stresses matter and these are different for waves, tides and density-driven flows.

The objectives, as stated, have not been fully achieved. We cannot discern whether there is a stage at which no further erosion may occur or what the size of a cuttings pile might be at this stage: the fate of the eroded material was not addressed. Neither slumping nor debris flow activity within piles can be ruled out on the basis of the findings presented.

TASK 3-2; DEPLETION STUDIES OF CONTAMINANTS IN DRILL CUTTINGS MESOCOSM SYSTEMS

The objective was to study the depletion of contaminants from cuttings piles surfaces under semi-natural conditions without physical disturbance, by use of mesocosms. The basic strategy of testing the degradation rates of cuttings piles components in a simulated seabed system is sound, and the same system has been used elsewhere with reliable results on oil-based mud (OBM) and synthetic oil-based mud (SBM) degradation. Also the attempt to compare cuttings piles samples with the surface-active layer intact to those where this was removed (i.e. “eroded”) is interesting. The failure to determine any loss of the cuttings piles total hydrocarbons (THC) by direct chemical analysis most probably was due to the following factors: high spatial heterogeneity of the test surfaces, low replication of the THC analyses and short duration of the experiment. The second set of experiments using sediment oxygen consumption (SOC) to estimate degradation appears to be far more reliable. The prime lessons learned from the study are:

- support for the slow surface loss of the OBM cuttings under undisturbed conditions (half-life in the order of more than a year),
- biodegradation (enhanced SOC) in the surface layer of SBM cuttings, but not in the OBM cuttings, and
- more rapid biodegradation of SBM in “new” surfaces exposed to the water as result of erosion.

TASK 3-3; AEROBIC AND ANAEROBIC DEGRADATION

The objective was to study aerobic and (assumed) anaerobic degradation of total hydrocarbons (THC) from a range of different cuttings by use of closed bottle techniques. The failure to detect any biodegradation of the cuttings piles hydrocarbons by chemical analysis of THC was most probably due to low replication of the analyses and high (and unknown) initial heterogeneity in THC content among bottles. The initial variability might have been quantified by preparing a set of replicate bottles in the same way and analysing these for THC immediately (rather than putting a lot of effort into post-experimental comparison of different analytical procedures). Realising that there was a possible unavoidable heterogeneity, and on basis of the among-bottle variance that was estimated, an attempt should have been made to assess the minimum change in THC content. This estimate could have been achieved with some statistical confidence despite the unsatisfactory present design (i.e. by power analysis).

The results show that the “anaerobic” test bottles in fact had dissolved oxygen (DO) in the water for most of the incubation period and that this oxygen was gradually depleted. Hence, the test cannot be regarded as showing strictly anaerobic degradation, as intended. This has been pointed out in the final report as well. The gradual reduction in DO over time was probably a result of aerobic degradation in the surface layer. Since some samples also showed an increase in sulphide content over time, anaerobic degradation cannot be ruled out in these bottles, but in general the indications of anaerobic degradation are somewhat weak.

TASK 3-4; RECOLONISATION

Short-term mesocosm experiments on recolonisation of contaminated sediments are difficult to carry out, because of both the difficulty of reproducing natural conditions and the slow rates of both degradation and recolonisation observed. The duration of these experiments was most probably insufficient to allow equilibrium levels of recolonisation to occur, since many generation times are required for this. Although some replicate measurements were made, little or no statistical analysis was undertaken, and no error estimates are available. The final report of this work is however, much more complete than the preliminary report reviewed earlier, and it includes a substantial and useful discussion of the results of the experiments undertaken. Overall the study has provided only little new information on recolonisation behaviour and rates, and the results are of limited value in relation the long term fate of piles. Long term *in situ* experiments are really required for reliable quantitative results to be obtained in future.

The experiments with *Capitella* were fairly successful (they are well known to be hardy recolonisers, although not necessarily very effective bioturbators), although this was not the original test species proposed. The experiment with *Abra alba* was less successful, since both shipments contained a large proportion of animals which were moribund on arrival. Although sufficient individuals survived for indicative results to be obtained, their behaviour cannot confidently be assumed to have been normal. Both test species seem to respond in the same differential way to the Beryl and the Ekofisk cuttings, which is reassuring. It is suggested that the reduced survival of *Capitella* in both the Beryl cuttings and the reference sediment is linked to starvation (rather than competition), which is plausible (it is suggested that they are feeding on bacteria degrading the synthetic mud in the Ekofisk trials). The correlation of burial depth with sediment conditions for *Capitella* is also an interesting result.

TASK 3-5; BIOTURBATION

In this work an attempt was made to simulate the effects of bioturbation in a mesocosm experiment. The experiment carried out involved mechanical raking of the sediment surface, at various rates, to 1 cm depth only. This did not conform to the approved proposal, which specified disturbance to several depth levels and use of an alternative form of disturbance (insertion of narrow tubes). Moreover, the rates of disturbance used (overturning to 1 cm depth every 14 days) correspond to a bioturbation rate of approximately 25 cm^2/yr, about 100 times higher than values inferred from field measurements, and are thus unrealistically high (and effectively infinite for practical purposes). No replication of the experiments or measurements were made, and so no statistical treatment of the results was possible. No acclimatisation or consolidation of the test plots after preparation and prior to the onset of raking was undertaken, so the results may not be representative of longer term effects. There are indications that the physical disturbance (without resuspension) that was imposed may have affected the sediment profiles of redox potential, and enhanced the total hydrocarbon (THC) loss from the surface, but the results remain inconclusive.

TASK 3-6; CHEMICAL BIOMARKER DEVELOPMENT

Drill cuttings materials contain a complex mixture of hydrocarbons, some of which are more susceptible to biodegradation than others. The objective of this study was to find out if the extent to which biodegradation occurs can be assessed by normalising any change in the total (gas chromatographically resolved) hydrocarbon concentration to that of a recalcitrant hydrocarbon (a chemical biomarker). This report details the use of a chemical biomarker based approach to the assessment of the biodegradation in two drill cuttings materials, namely from Beryl A (an oil based mud, OBM) and Ekofisk (a synthetic based mud, SBM).

The report concludes that hopane-type hydrocarbons are the most resistant chemical biomarkers towards biodegradation in crude oil-related fluids. This has been textbook knowledge for about two decades. The reports also concludes that these hopane biomarkers, again not to any surprise, cannot be used for SBM cuttings material, because these compounds are not constituents of synthetic oils.

The study, thus, has neither provided any new information nor has it found a solution to the problem of widely applicable biomarkers for studying progress in biodegradation in cuttings piles with different compositions of the drilling mud fluids.

TASK 4; ADAPTATION AND EVALUATION OF MATHEMATICAL MODEL

The Scientific Review Group considered that the development of a mathematical model was a key element of the Drill Cuttings Initiative. It was anticipated that the model would integrate outputs from several of the other Tasks leading to a tool that could be used to make predictions of the fate of the cuttings piles and their contaminants over time. In the end some of the model's Case Study runs were delayed until towards the end of the Initiative and there was little time to complete the computer runs, interpret the results and produce the final report.

The Scientific Review Group considers that this time pressure is reflected in the final report in that some of the explanations of the processes being modelled, the choice of parameters and anomalies in the results could have been more clearly described had the Contractor had more time.

While the modelling of the various physical and biological processes represented in the model and the form of the numerical solution are not new in themselves, as far as the Scientific Review Group is aware they have not hitherto been assembled in this way nor applied to the drill cuttings problem. The work thus represents an important step forward. It should be seen as a good foundation from which to develop a more reliable operational model.

There are a number of shortcomings in the work that are recognised by the Scientific Review Group and some of these have been identified by the Contractor. The data set used to define the parameters for the model is poor. A set of experimental studies aimed at producing data to meet the modellers' needs was established under Task 3 but the results from these were generally disappointing. Model parameters therefore had to be selected either by using the limited data from Task 3 or gleaned from the literature or intuition. The Scientific Review Group, recognising that there would be some difficulty in parameter selection, suggested at the onset of Phase II of the work that sensitivity tests to explore a range of parameters were required for the model runs. These were made, are described in the report, and give some insight into the relative importance of the different processes. However the report does not fully describe the rationale behind parameter selection and has not used some laboratory-generated parameters (e.g. on experimentally measured shear strength) where intuitively chosen parameters have been used.

Six case studies were run to explore the long-term fate of the cuttings piles and their contaminants. These examined large and small piles in varying depths of water. The further spread and degradation of cuttings material transported to the 'far field' was also examined. The Scientific Review Group is concerned that all the model runs for the case studies were made with only one set of parameters. Sensitivity tests examining behaviour for a range of parameters are required but the Contractor did not have time for these. The outputs from the case studies therefore give only a qualitative indication that the processes described are moving in the right direction. The significance of the results must not be overstated and they should not be used at this stage of model development to determine policy or operational practice. It has been pointed out that there are some 'model artefacts' in some of the results, and there is reference to 'semi-quantitative adjustments'. These appear to be associated with the numerical method that is used and the way the processors are represented within a fixed grid. Such anomalies need to be removed before the model can be used operationally.

The Scientific Review Group also noted that there are a number of potentially important processes not yet represented in the model, e.g. erosion and re-deposition of the clean sea bed sediment surrounding the pile, widespread natural sedimentation processes in the North Sea, and consolidation of the cuttings pile material. The model uses a stochastic distribution of bottom currents from storm waves, tidal and other currents to force erosion once a threshold is exceeded. However, the relationship between the critical erosion bottom stress threshold and the current which gives rise to it is different for the three forcing factors, both separately and in combination. It is critical to represent the erosion process as accurately as possible, since it controls removal, of cuttings, transport, resettling and mixing with adjacent seabed sediments, as well as exposing further contaminated cuttings to aerobic processes in the pile surface active layer. This is an area for further model development in the future.

A valiant attempt was made to assemble information from field data on the erosion rates of cuttings piles in order to attempt some validation of the model. However such data as are available are difficult to analyse, and convincing validation of the model has not yet been possible.

In summary, the Scientific Review Group considers that the work conducted in producing the model is good, but that the reporting on it could have been better. At this stage the results can only be viewed as indicative. There is a need to incorporate additional processes in the model, modify numerical procedures to remove 'artefacts', and seek additional data to improve model parameterisation and validation. The Scientific Review Group considers that an extension of the modellers' work is necessary, but that this also requires an input from a wider range of disciplines so that parameter selection is based more securely on relevant experience, and the model's output can be subject to further expert and impartial scientific review.

TASK 5A; IN-SITU SOLUTIONS: ENHANCED BIOREMEDIATION

The coverage of the report conforms in general to the prescribed specifications. It deals with two aspects:

- the biological feasibility and effectiveness of aerobic bioremediation of hydrocarbons in oil based cuttings by use of aeration and addition of nutrients,
- technical design specifications and operational cost estimates for a bioreactor system to be used *in situ* to remove hydrocarbons.

The comments by the Scientific Review Group focus on these two aspects, with a comment also on the legal aspects of this potential solution.

Only one experiment on biodegradation was performed, and this used a sample from a cuttings pile with oil content at the lower end of the range encountered. Thus statements about discharge concentrations after biodegradation treatment are speculative. Earlier studies have shown that the degradation rate of base oil components is inversely related to oil concentration on cuttings. This tends to make this experiment a ‘best case’ and leads to optimistic assessments for more contaminated piles. Also the design of the proposed reactor vessel differs in several respects from the experimental one. The volume of (static) water to cuttings in the experiment was 20:1 whereas the reactor is designed to operate at 1:1 and with water which is renewed periodically. The impacts of these differences on rates of degradation are unknown.

The title of the project is bioremediation solutions, but the rapid loss of hydrocarbons during the experiment may include physical removal of oil from particles into the water phase, in solution or emulsion, by a scrubbing process, as the report now concedes. The initial loss of added nutrients in the first week is the only signal of biological degradation.

A temperature of 19°C was maintained during the experiment, which is much higher than that encountered *in situ*, and a study of the temperature/rate dependence would have been useful. If the main process was scrubbing, the influence of temperature would be totally different.

In the sediment toxicity test it is not clear whether the data have been corrected for intermittent deaths, and whether the LC_{10} value for treated sediment of 18.3% has been corrected for this. If it is, there is still substantial toxicity, which has legal implications for the dumping of the 'cleaned' material.

The design of the reactor system including topside equipment is mostly based on assumptions related to degradation efficiency. It is uncertain whether the removal of oil contamination from the cuttings material is mostly biodegradation or scrubbing, and both will be in action. For the purpose of cleaning it does not matter, but the term 'reactor' should not be used unless biodegradation dominates. In order to optimise the technical design it is essential to know this.

No convincing case is made for the reactor vessel being placed on the sea floor. There is no inherent reason why it could not be at sea surface level, on the platform or a suitable barge/ship. Having the reactor at the surface would have thermal and control advantages.

On the basis of the uncertainties above it seems impossible to estimate the time with any confidence for satisfactory remediation for a batch of cuttings transported to the reactor. The metals will also not be remediated by the process offered. Without any experimental data the assumption in the cost calculations that no extra treatment of the water for metals is necessary has no basis.

For this treatment option to be used it would be essential to have an acceptable (to OSPAR) upper threshold concentration of total hydrocarbons (THC) (and other components) in the treated material returned to the seabed. The criteria used in the report, i.e. 400 mg THC per kg dry weight, relate to land disposal and do not apply in the marine environment where the apparent threshold for effects on benthic fauna is around 100 mg THC per kg. If land disposal is the option taken for the treated material, one must question whether offshore treatment and transport with twenty times the volume of lifted water is economic compared with the transport of untreated material.

TASK 5B; IN-SITU SOLUTIONS: COVERING

Task 5B involved a study of the use of *in-situ* coverings to remove the problem of slow leaching of the contained oily waste material in drill piles to the environment. The report investigated in detail a covering of natural materials using an initial layer of sand, an intermediate layer of gravel to act as a filter, and a protective layer of rock armour. It showed clearly that this is a feasible option for steel structures that have been fully removed and for some that are partially removed. Alternative materials such as membranes, mattresses, concrete, resinous and bituminous materials were also considered but shown to be more difficult to apply, costly and to offer no benefits over natural materials. *In situ* geotechnical properties were considered and this work was supported by additional test data. In general it can be seen that the full extent of the geotechnical properties through the pile is seldom available, and this is a limiting factor in determining the geotechnical constraints to covering. One problem identified was that some piles had a steep slope in the central region and that this would be a limitation to covering. 'Building out' in this region was suggested but removal of part of the pile is also an option.

. The Scientific Review Group successfully argued for a Phase 2 of this approach and this report justifies that confidence. It is an excellent report and describes a technique that is potentially very useful for the drill cuttings pile problem. The report correctly identifies the necessity of on-going monitoring of cuttings pile sites.
A wide variety of erosion or deposition conditions exist in the North Sea and studies will be needed for individual cases. The study looked at three particular cases located in the Central and Northern North Sea and showed that all were feasible. However it is of interest to note that rock dumping will provide a step *increase* in resistance to erosion compared to existing drill cutting pile materials. It is therefore unlikely that material dumped on piles that have been in existence for many years will move.

In situ covering may not be applicable for all platforms. Some platforms may require a combined approach with some lifting (e.g. around jackets prior to removal) and then covering. Careful consideration would need to be given to the extent of covering (i.e. at what minimum thickness of pile around the edges may covering become unnecessary).

Pathways for pore fluids other than vertical were not considered but should have been, and the reviewers had some problems with the methods and results of chemical analyses used by the contractors, but overall these do not alter the principal conclusions.

Prior to covering, a full survey of the geotechnical properties would be necessary. A pilot study of properties throughout the pile for a few representative piles should be undertaken.

TASK 6; PILOT LIFTING OPERATION

The objective of Task 6 was to develop and field deploy drill cuttings recovery equipment, and to monitor the environmental impact of removal. This report covers the first of these objectives. The study involved an equipment tender exercise, an onshore trial (attended by members of the Scientific Review Group), a further development of dredging heads, and finally the offshore trial.

The study was completed and a short but successful offshore trial was conducted showing that lifting of drill cuttings in the Northern North Sea using a platform based ROV system was quite feasible.

In simple terms two dredging heads were used, a cutting head and a suction dredge head, of which the latter was more successful and was used for the majority of the trials. Blockage appeared to be a common feature, back flushing to clear blockage was the major environmental impact, and the water to solids ratio was high (overall average 25:1). Moreover, the availability of wells for reinjection suggested that this technique could be limited to a few situations. Other findings included confirmation of the amount of oil in the pile, and that oil was generally attached to particles so that only a small amount was released into the sea..

Environmental monitoring equipment was deployed and operated successfully, but the data proved rather ineffective in terms of defining the plume because the sensors were too sparse to cover the space occupied by the plume most of the time. Video coverage of the cutting tools indicated little spillage or plume creation during suction, but a definite plume when back flushing occurred. This is a valuable observation, because it indicates that, for piles of this type, pollution during lifting could be low if back flushing can be eliminated or minimised. Unfortunately very little quantitative information was produced that could be used to validate plume persistence/dispersion models.

The suction and cutter heads appeared to work very well and, during normal operation, seemed to give only a small plume. The utilisation time was low but this is a new technique and it would appear that given time the ROV operators would be able to improve the solid/liquid ratio and the utilisation time. The approach would seem to be very suitable for small tasks, for instance pile leveling, but may be more difficult when large volumes have to be lifted (because of the high water/solid ratio and the disposal problem).

The current systems do not appear to be likely to give the optimum desired water solid ratio of 3:1. Water entrainment during use of the suction head is always likely to be high and it is desirable that alternative systems be considered that involve say a combination of seabed mechanical lifting to a mixing chamber that can give a controlled liquid solid ratio before recovery to the surface. Lifting (and polluting) excess water is highly undesirable and needs to be avoided to the maximum extent possible.

The Scientific Review Group suggested at an early stage that the major environmental impact would come from the release of the material in the pipe linking the platform to the ROV. This proved to be the case and arose from blocking of the suction head rather than equipment malfunction. Back flushing to clear a blockage was quite common during the trial and unless changes are made to the operational procedure, this will persist as a problem. Some attention needs to be directed towards a more localised backflushing so that the extent of the release is limited to small volumes of material.

Both the Warman pump and the Discflo pump were deployed and used successfully. The performance appeared to be similar apart from flow rate and this would not seem to be a problem area.

The ROV operated successfully and did not appear to be a significant cause of pollution for this particular drill cuttings pile. Visibility appeared to be good throughout the trials and some excellent videos were produced showing the dredging heads in operation.

In normal use the wells are specially designed and constructed to accept a stream of cuttings for reinjection (often at medium depth formations). In the offshore trials at NW Hutton there were no wells designed for reinjection and it was necessary to select a suitable candidate from those used for water reinjection. In the event the SWACO system worked well but the reinjection was limited to recovered water. This highlights the possible problems associated with reinjection and it is likely that this approach will only be possible in certain cases and will have high cost implications. The conclusion to be drawn from this is that alternative routes for disposal (onshore) will be required in many cases if lifting is considered necessary.

It was noted with concern that very little information was available in the report on the extent of the plumes that occurred during back flushing. Such information will be a valuable aid to modelling possibly allowing extrapolation of likely pollution levels to other sites. In this respect, data on the prevailing sea states, quantity and nature of the discharge, height of discharge from the seabed, extent of travel and persistence of the plume would have been very valuable. Validation of models from an offshore trial would have been an extremely valuable output from this work. It should be attempted in any further trials.

The Scientific Review Group recommends that ,in any future work, alternative dredging systems should be explored that can give a controlled liquid solid ratio before recovery to the surface. Furthermore, collection of environmental data for the specific purpose of plume model validation should be attempted in future trials. Finally, alternative back-flushing systems should be explored to avoid extensive release of contaminated material to the environment.

TASK 7; EVALUATION OF OPTIONS FOR SLURRY HANDLING OFFSHORE, TRANSPORT TO SHORE AND ONSHORE PROCESSING

Task 7 assesses and compares the various options for treatment of removed cuttings and associated water. Both offshore and onshore treatment options were considered.

In total six treatment options were identified and compared using a high level *Best Practical Environmental Options Study* assessments method. The report shows that no single option was obviously superior and all had some drawbacks. The report concludes that only three of the options are viable and these are considered here.

Drill cuttings reinjection is the most attractive from the view of minimising the amount of transport, and waste disposal onshore, but is not usually legal under current regulations, and is not simple as seen in Task 6. It was noted that it is viable at only 25% of UK installations which implies that if all cuttings must be lifted one of the other alternatives would be the main process to be used.

Separation offshore, with disposal of water offshore or transport with solids to shore are the remaining options. Shipping large amounts of slurry to shore and subsequent disposal were identified as the main problems. The increase in polluted material produced due to lifting makes the other approaches such as covering more attractive if reinjection is not practical.

The report is very thorough and has considered the six options in great detail and comes to some very sensible conclusions. The report is clearly targeted at solutions for NW Hutton. More consideration could have been given to the amount of water that might need treatment (the NW Hutton trial showed a very high water/solids ratio, much greater than new cuttings reinjection processes would experience), and other situations where the platform cannot be used.

Injection of cuttings would appear to be the best option for an operational platform as in the case of NW Hutton but even here there are problems and these have not been considered. Reinjection of water was achieved and this may be a more common sub option (together with solid treatment onshore). In addition, the amount of water lifted with the cuttings made the water/solids ratio very different to that for fresh cuttings. This was not considered and may introduce a fresh sub-option for this solution. The circumstances under which it is possible to use this option should have been considered in more detail.

Transport of slurry to shore, separation and treatment onshore is the simplistic solution which may be necessary but the drawbacks need to be fully investigated. The use of large trailer dredgers in close proximity to platforms may be a problem. This needs to be discussed in detail in terms of risks and previous experience. In addition, every step produces more polluted material which either needs treatment or has to be disposed. The final step involving road transport and landfill is not insignificant and the downside needs full emphasis. The response of local residents should not be underestimated.

Separation, treatment of liquids offshore, transport and treatment of solids onshore is the intermediate solution where the water treatment is conducted on the platform. The difficulty with this option is the operational feasibility (i.e. large number of personnel offshore). Obviously, without an operational platform the offshore separation and treatment is very difficult. The restriction of conclusions of this study to NW Hutton needs emphasising as many people may not read the whole report.

1st Meeting - 12/13th June, 2000

Review of proposals. The views of the Scientific Review Group were available to the Executive Committee when contractors for the research tasks were selected. In some cases, the Scientific Review Group suggested changes to the work proposed, the intention being to enhance the value of the results obtained, or requested clarification of the approach intended..

2nd Meeting - 14/15th May 2001

Review of initial batch of research reports. Sufficient time was available for these reports to be reviewed and for comments made by the Scientific Review Group to be considered and incorporated before the next meeting.

3rd Meeting - 2/3rd October 2001

Review of second batch of research reports. In addition to reviewing the later drafts of the initial batch of reports, the Scientific Review Group reviewed most of the remaining reports but at various stages of their development. At the time of the meeting, some reports had been considered by the Executive Committee and the Committee's comments incorporated, some reports had been considered by the Executive Committee and the Committee's comments were given to the Group with the first draft of the report and some reports were only available just in time for the meeting.

Within the time constraints, the Scientific Review Group commented as best it could and individual members continued to interact with the authors of reports to ensure that the best scientific evidence was presented.

4th Meeting - 21st November 2001

Review of Draft Final Reports. Scientific Review Group members had attended the Stakeholders meeting the previous day, taking part in the various activities. Their overall view was that the day had been successful in conveying a good appreciation of the scope of the JIP but the exercise to obtain feedback on the main conclusions did not seem to have been as informative.

When considering the draft final reports for the Tasks, the Scientific Review Group observed that these were not complete in some cases and further interaction with the authors would be necessary. Members of the Group were assigned to specific Tasks, to liaise with the authors where necessary and to prepare a summary of the Group's views for that Task. These summaries were collated and sent to the authors for further action as required. A significant amount of work remained to be completed for Task 4 and the Group was only able to comment briefly on the results of sample studies that had been presented to the Stakeholders meeting.

5th Meeting - 18th January 2002

Review of Task 4 Final Report and discussion of the Scientific Review Group Final Report. Since the previous meeting, members of the Scientific Review Group had reviewed parts of the Task 4 Final Report as they became available, but always under very tight time constraints, resulting in a number of comments on the unsatisfactory nature of the review process under these conditions. Consequently, a representative of BMT attended the first part of this meeting to discuss the comments made on Task 4 by the Scientific Review Group.

Following this, the Scientific Review Group reviewed a draft of its own Final Report and the detailed comments it wished to make on the reports for the various Tasks. These comments are attached to this report as Annex 1.