# ENVIRONMENTAL ASPECTS OF USING FRESH PFA AS FILL IN RECLAMATION

GEO REPORT No. 53

K.S. Ho & P.Y.M. Chen

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
HONG KONG

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# PREFACE

In keeping with our policy of releasing information of general technical interest, we make available some of our internal reports in a series of publications termed the GEO Report series. The reports in this series, of which this is one, are selected from a wide range of reports produced by the staff of the Office and our consultants. A charge is made to cover the cost of printing.

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A.W. Malone
Principal Government Geotechnical Engineer
August 1996

# FOREWORD

This report documents a review of environmental aspects of using fresh PFA as fill below water in reclamation. It describes the prevailing state of knowledge and provides some suggestions for environmental assessment of such a use of PFA. Dr. P.Y.M. Chen commenced the review in early 1994 and proposed guidelines for environmental control, monitoring and estimated associated costs for testing. Dr. K.S. Ho took over the work in mid 1994 and completed the report. Both of them worked under the general guidance of Dr. J. Premchitt.

Y.C. Chan
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## ABSTRACT

In response to concerns raised by the Environmental Protection Department, a study has been carried out to examine the environmental aspects on the use of fresh PFA as fill material below water. Overseas studies, laboratory trials and case studies in Hong Kong on the use of PFA in marine conditions have been reviewed in this report.

Six laboratory trials and case studies in Hong Kong on the use of PFA below water have been reviewed. However, only a small proportion of data refer directly to the use of fresh PFA under water and therefore, the corresponding environmental impact cannot be fully assessed.

Review of study results overseas and comparison with a set of fill quality guidelines from North America do not reveal major environmental problem especially if contamination of open seawater is minimised by placing the PFA in water confined by properly designed seawall. However, there remain some areas of insufficient information, and until these remaining concerns are removed, the use of fresh PFA in marine reclamation has to be accompanied by a scheme to monitor environmental impact.

A set of environmental guidelines has been proposed based on the scheme used for Urmston Road project, including a monitoring scheme to provide the needed field data. It is also suggested that some simple laboratory tests on the fresh PFA sample itself may be used to verify the suitability of the PFA for marine filling with suitable acceptance criteria, on similar basis to that used for lake fill material in Canada. Such tests could be used to supplement and finally replace the time-consuming monitoring requirements.

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## 1. INTRODUCTION

The two power companies in Hong Kong currently produce about one million tonnes per annum of Pulverized Fuel Ash (PFA) as a by-product of coal-fired electricity generation, and the annual production is expected to increase in the future. This material needs to be disposed of in a satisfactory manner. If beneficial use cannot be found within the construction industry, long stretches of the shoreline will have to be occupied by expanding purpose-built disposal lagoons, preventing any future development of the area.

Extensive laboratory studies and actual usage of PFA in the field, both overseas and in Hong Kong, have demonstrated the suitability in terms of geotechnical aspects of PFA as a fill material. It has a grain size distribution and general engineering properties similar to those of natural silt or silty fine sand. However, it has a much lower unit weight, and therefore has an advantage over other materials in works that require lightweight fill. PFA has already been used as an engineering material in a number of land formation projects in Hong Kong, mainly at sites in the northwest New Territories, including a foreshore reclamation at Area 47S, Tuen Mun. However, the amount of PFA used as fill below water has so far been small; for example, it was used as lightweight fill for the approaches to the Eastern Harbour Crossing and for the reclamation as part of the works for the submarine outfall to Urmston Road in Tuen Mun. Some recent projects using considerable quantities of PFA from China Light & Power Co. Ltd. (CLP) are summarized in Table 1.

The use of PFA in reclamation has been reviewed in GEO Report No. 24. This report indicated that, in terms of geotechnical engineering properties, PFA can be used as fill in submarine conditions.

According to the Works Branch Technical Circular No. 14/94 dated 22 July 1994 (Appendix A) "Use of PFA as General Fill in Reclamations", PFA leached in the lagoon for not less than two years (lagooned PFA) is acceptable for use as reclamation fill. In the use of lagooned PFA in reclamation, it is required that suitable operational procedures should be adopted and the selected site is not environmentally sensitive.

For newly-produced PFA ("fresh" PFA) and the PFA leached in the lagoon for less than two years, they are not acceptable for use as fill below water until its environmental acceptability has been demonstrated by suitable field trials. The use of fresh PFA as fill below water will be assessed by the Environmental Protection Department (EPD) on a case-by-case basis.

In order to ensure the efficient utilisation of all types of potential fill materials and to investigate the use of PFA for this purpose, the Special Projects Division has carried out a study to examine the current restrictions on the use of fresh PFA as fill material below water. The main objective of this project is to study the environmental aspects of using PFA as fill in marine reclamation. This report is a documentation of the following work:

(a) Review of the chemical properties of deposited PFA in marine condition

(b) Review of overseas studies

(c) Review of laboratory trials and case studies in Hong Kong

(d) Review of relevant guidelines

(e) Proposal of suitable measures to mitigate against unfavourable environmental effects, if any.

The study of the detailed environmental control criteria and environmental monitoring scheme for the use of fresh PFA as fill under water for specific construction projects are outside the scope of this report.

## 2. CHEMICAL CONSTITUENTS OF PFA AND THEIR ENVIRONMENTAL IMPACT

PFA is formed from rock detritus present in coal. This detritus consists of clays, quartz, pyrite and mixed carbonates of calcium, iron and magnesium. The predominant constituents of PFA are oxides of silicon, aluminium and iron, most of which are in a glassy state. Other constituents include calcium, magnesium, potassium, sodium, sulphur, trace elements and unburnt coal. The chemical composition of dry PFA from the Castle Peak Power Stations over the period from 1985 to 1989 is given in Table 2 along with data from other sources for comparison. The chemical composition of the ash is influenced by properties of the source coals and by burning conditions.

Minute quantities of a number of trace elements (Parker 1989) present in PFA and include arsenic, cadmium, chromium, copper, lead, selenium, zinc and boron. Data for dry Castle Peak PFA along with data from other sources are presented in Table 3.

The release of contaminants into solution from a material will depend upon the contaminant solubility, the contact time with the washing water and whether equilibrium between the solid and liquid state is achieved during that contact time. Solubility is further governed by the acidity of the washing water, oxidising or reducing conditions, the partial pressures of oxygen and of carbon dioxide and ionic strength.

The major constituents which can be leached from PFA are calcium, sodium and sulphate, together with smaller quantities of potassium, magnesium and chloride. However, the principal concern relating to leachate from PFA is the heavy metals concentration. These include the metals such as iron, copper, cobalt and manganese, which for some organisms are essential in low concentration but may be toxic in high concentration. In addition, there are metals such as mercury, lead, tin, cadmium, selenium and arsenic, which are generally not required for metabolic activity and are toxic to organisms at quite low concentration. These tend to be concentrated on the surface of PFA particles and are therefore potentially readily available for dissolution (CLP 1990).

The significance of trace elements (Parker 1989) leaching is that, in the marine environment, there are organisms which may continuously take in and accumulate these toxic metals (bio-accumulation), particularly where these organisms form part of the food-chain leading to humans. Shell fishes usually bio-accumulate heavy metals and are sometimes used as indicators of water pollution. Oysters are usually used by the power companies to monitor heavy metal concentration in the sea around the power stations. For reference, the acceptable

metal levels in sea food in Food Adulteration (Metallic Contamination) Regulations 1983 of the Hong Kong Government are summarized in Table 4, and the recommended value (WHO, 1984) for health-related inorganic constituents in drinking water are summarized in Table 5.

## 3. REVIEW OF OVERSEAS STUDIES

In the United Kingdom, large quantities of PFA were disposed of by dumping into the sea. Investigation work has been carried out in the United Kingdom to study this practice. Bamber (1980) reported his studies in the assessment of the physical and chemical characteristics of the ash in relation to the marine benthic environment.

Bamber (1980) indicated that PFA is chemically similar in nature to naturally occurring sediments. Toxic chemicals such as heavy metal and organic compounds are not significantly present in PFA. The PFA sediment samples tested were found to have no detectable effect on the environmental pH in the marine situation. No organic matter was found at the dumping site.

Bamber also noted that the silty nature of PFA may restrict its suitability to colonisation by diverse fauna species. The fine particle size may also restrict its suitability by affecting the metabolism of infaunal species, as in the inhibition of feeding due to the ingestion of large amounts of sedimentary material. The fine particle size renders PFA vulnerable to re-suspension, and thus dispersion over the seabed by current or wave action. However, PFA is usually placed in water confined by a bund or seawall and such effect will be minimum.

It was concluded by Bamber that PFA placed below water as fill is chemically (environmentally) appropriate, and is comparable to a homogeneous fine mud (namely its effects on environment should be comparable to that arising from homogeneous fine mud).

A fill quality guideline, "Fill Quality Guidelines for Lakefilling in Ontario, Application of Sediment and Water Quality Guidelines to Lakefilling", was introduced by the Ontario Ministry of Environment in Canada (1992). This guideline will replace the existing Open Water Disposal Guidelines. Any materials to be used as fill under water must meet the requirements of the fill quality guidelines. These guidelines provide good example of the control in Canada where the environmental practice and standard are one of the highest and most stringent in the world. The guidelines in other countries such as Hong Kong may be somewhat different depending on local conditions.

The purpose of these guidelines is to protect the quality of the water in the lakes in Ontario and to minimize pollution from occurring in the future. The materials which may be used for lakefilling projects are divided into two categories, viz. confined fill and unconfined fill.

Confined fill may be used for lakefilling projects provided it is placed within the confines of a structure, such as a dyke, which is capable of withstanding the waves of a 1-in-50-year storm. The idea is to prevent the fill from coming into contact with open water and, in the event of a storm or high waves, being washed away. Material for use as confined fill must meet the Interim Confined Fill Guidelines as shown in Table 6.

Unconfined fill which may be placed directly into the water must pass a set of tests laid down in the guidelines.

Table 7 summarizes the results of total metal analyses undertaken on solid PFA samples from CLP for the SENT Landfill trial. When comparing the metal contents of fresh PFA with those listed in Table 6, it can be seen that the concentration of heavy metals measured from the fresh PFA sample are within the limit laid down in the guidelines. There are variation of PFA properties with time due to changing sources of coal. Therefore, for this type of test, regular sampling and testing will have to be done to ensure continuing acceptability.

## 4. REVIEW OF STUDIES IN HONG KONG

PFA has been studied for use as fill below water in several projects in Hong Kong. The following sections summarise the findings of a review of the available records of the laboratory trials and case studies of the use of PFA.

### 4.1 SENT Landfill

The option of using PFA as a marine fill for part of the land reclamation for the SENT Landfill development was considered by CLP and laboratory trials were undertaken in December 1991 to assess the potential environmental impact and suitability of using PFA from CLP for this purpose. Both lagooned and conditioned PFA were tested in the trials. Laboratory-based leaching trials, using seawater collected near Tseung Kwan O and deionised water, were carried out on PFA obtained from the CLP power station at Tap Shek Kok. Details of the test results are documented in CLP (1991).

The PFA leaching trials were based on a test devised in the United Kingdom and involved repetitive batched shaking tests (CLP 1991) in order to assess both the short and long term leaching characteristics of PFA. These tests were carried out using a high solid-to-liquid ratio, based on the concept of "bed volume" (i.e. the volume of leaching fluid required to just cover and render mobile a sample of the material).

At the time of the trials it was understood that the only suitable source of PFA available in sufficiently large quantities for use at the SENT Landfill was lagooned PFA from Tsang Tsui. The batched shaking tests were carried out on samples of the lagooned PFA. For comparison, two samples of fresh PFA were also tested. These fresh PFA samples consisted of a composite of PFA arising from burning of twelve coal types at different times, and PFA originated from a single coal type.

The results of the trials indicated that only low concentration of potential contaminants were leached into solution. The contaminants with the greatest tendency to leach into solution are cadmium, chromium and aluminium. For cadmium, metal concentration in the leaching fluids ranged from 0.002 mg/l to 0.030 mg/l. Chromium concentration ranged from 0.060 mg/l to 2.300 mg/l and aluminium concentration from 0.5 mg/l to 27 mg/l. Overall, the results indicated that when seawater was used as leaching fluid with lagooned PFA, the metal concentration in the leaching fluid was found to be the lowest.

For the test on fresh PFA, an initial flush of metals occurred in the first bed volume. The test results indicated that this initial flush of metals is likely to vary from one PFA type to another. For this reason, the environmental consequences of using fresh PFA were less easy to predict. On the contrary, the results from the lagooned PFA tended to show smaller variations between the first and successive bed volumes, and metal leaching was more consistent. For this reason, lagooned PFA was classed by CLP (1991) as the "Best Environmental Option" for use at the SENT Landfill. This term only applies to the comparison of the test results on the two major types of materials (fresh and lagooned PFA) described in the report (CLP, 1991).

In assessing the use of PFA as a fill material, reference was made to the Environmental Protection Department's Technical Memorandum on Standards for Effluents Discharged to Drainage and Sewerage Systems, Inland and Coastal Waters (January 1991). Although not strictly applicable to land reclamation, the standards listed in this document had been used for reference. Based on the daily rate of placement of PFA and the assumption that a volume of water equivalent to the volume of PFA deposited would be displaced from the reclamation area, the effluent standards applicable to a flow rate of between 800 and 1000 cu m per day was used for comparison (see Table 8).

The results presented in this report indicate that, in the leaching trials, the metals of principal concern were cadmium and chromium. The maximum cadmium concentration measured for the lagooned PFA in seawater was 0.004 mg/l, which represents a concentration four times greater than the effluent discharge limit of 0.001 mg/l. For chromium the maximum concentration measured was 0.3 mg/l in the first bed volume. This lies below the effluent standard for individual toxic metals of 0.5 mg/l.

Despite the elevated concentration of cadmium in the leaching solutions the report considered that this should not preclude the use of lagooned PFA as a reclamation material, and that under properly controlled conditions its use at the SENT Landfill is acceptable.

Although the experimental results show that the "Best Environmental Option" at the SENT Landfill is the use of lagooned PFA, the report suggested that the use of fresh PFA under similar controlled situations may prove equally acceptable. However, this suggestion was made with the qualification that any decision to place PFA below water in reclamation must be made on a site-specific basis and with regard to the particular conditions.

The SENT report also made the following conclusions:

(a) If PFA is to be used for marine reclamation at SENT, the lagooned PFA should be pumped in slurry form into the reclamation area, after completion of the seawall. PFA would then be disposed of in a closed environment with only controlled openings to the sea in the form of screened drainage culverts.

(b) The discharge of water from the reclamation should be monitored through collection of weekly seawater samples at the culvert outlets, and analyzed for cadmium and chromium in order to ensure that sufficient dilution of the PFA

leachate has occurred within the reclamation area. A full range of potential contaminants should be analyzed on a monthly basis until the reclamation is complete.

## 4.2 Urmston Road Outfall

The Contractor, Shui On-Boskalis Joint Venture proposed to the Civil Engineering Department (CED) and the EPD through the Engineer (Mott MacDonald) and the client office (Territory Development Department, North-West New Territories) to use PFA to construct a reclamation as part of the works for the outfall to Urmston road that forms part of the North West New Territories Sewerage Scheme (under TDD Contract No. TM 70/88). The feasibility study and the design of the reclamation were carried out by Au Posford Consultants Ltd. The project involved PFA filling below as well as above water. The site is near Black Point, Tuen Mun, and the reclamation area is approximately rectangular with a length of 260 m parallel to the shoreline and a width of 145 m. About 250,000 $m^3$ was placed over a period of several months. The area was then capped by 1 m of fill material. The site was used largely as the Contractor's works area, and might be incorporated into the Tuen Mun Port Development area in about five years' time. Reclamation started in November 1991.

In this project, EPD required a three-year post-reclamation monitoring. However, the contractor indicated that they could not extend the monitoring programme beyond their contract completion date, i.e. December 1992.

In the end, although some tests were carried out from July 1992, there was no monitoring data after March 1993. The monitoring was incomplete as only two partial sets of data were taken against the possible maximum of eight sets. The small amount of submitted data was incomplete and was submitted without appropriate interpretation. Therefore the environmental impact of the use of PFA fill below water cannot be fully assessed for this project.

## 4.3 Lamma Quarry Restoration

Leachate tests and marine monitoring were carried out by Binnie Consultants Limited, on behalf of Hongkong Electric Company Limited (HEC), as part of the testing and monitoring for the Lamma Quarry Restoration Trial in 1990 (Figure 1). The purpose of the trial was to investigate the feasibility of restoring the quarry at Sok Kwu Wan using PFA, thus providing a means for disposal of ash produced at the Lamma Power Station. The trial proved that "fresh" PFA could be used as landfill adjacent to the sea without severe pollution of the sea, provided that adequate precautionary measures are taken during the transportation and placing of the PFA, and provided that the PFA is contained within bunds with cut-off layers and leachate collection systems. Details of the results of tests carried out as part of the trial are documented in HEC (1991).

The Lamma Quarry Trial used fresh PFA as landfill. Although there was marine monitoring and leachate testing, the trial did not provide sufficient information to assess the environmental impact of the use of PFA for reclamation below water.

## 4.4 Siu Lang Shui Coal Ash Disposal Sites

During the period between August 1986 and August 1987, CLP carried out environmental monitoring of drainage water from the Siu Lang Shui Coal Ash Disposal Sites (Figure 2). The two sites (Site A and Site B) in question are located in a coastal valley, a short distance to the east of Castle Peak Power Station. Both sites were constructed with underlying drainage systems, each of which converges on its own individual discharge collection point (Figure 2) before discharge to the sea. The use of the sites started in December 1985 and was completed in May 1987 with an estimated volume of 400,000 $m^3$ of conditioned PFA (fresh PFA with added water) in place up to depths of about 20 m. The sites were then covered by soil and landscaped.

Leachate was collected during the monitoring period at the two drainage collection points at monthly intervals but only when sufficient rainfall caused a constant flow at the points such that meaningful sampling could be undertaken. A number of parameters of environmental interest in the drainage water, such as total suspended solid (TSS), pH, chloride ($Cl^-$), sulphate ($SO_4^{2-}$), sodium (Na), boron (B), arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), molybdenum (Mo), and selenium (Se), were determined.

The test results indicated that drainage water from the Siu Lang Shui sites was not a source of environmental concern. In the samples tested, the metal content of some elements such as As, Cd, Cr and Pb (which are harmful to health) were found to be well below the limits laid down in the "Draft Interim Effluent Guideline" of the EPD proposed in January 1984. When the metal contents were compared with the drinking water guidelines, only one of the duplicate samples was found to be outside the recommended limit with respect to chromium content.

It was concluded in this report that the use of PFA from Castle Peak Power Station in reclamation or landfill projects is unlikely to present a significant environmental risk. Environmental monitoring of the same sites were carried out again between July 1988 and January 1989. In addition to the sampling procedures used in the earlier monitoring, this second phase of the monitoring programme also included analyses of stream water which did not come into contact with the ash strata. This additional sampling and monitoring programme is to gain information on background concentration in the area for the purpose of comparison.

The second phase study indicated that the levels of B, Cr, Mo, Na, $Cl^-$ and $SO_4^{2-}$ measured at the disposal sites were largely originated from the ash, rather than the background source of the area. The 12 parameters measured were found to remain within the limits laid down in the "Draft Interim Effluent Guidelines" and the "Guidelines for Drinking Water Quality".

## 4.5 Tsang Tsui Ash Lagoons

The Tsang Tsui Lagoons, which are operated by CLP and used for the storage of PFA from Castle Peak Power Station, occupy adjacent sites on the coast of Deep Bay. They are designated the West, the Middle and the East (Figure 3). Impermeable membrane was installed in the seawall to separate PFA from the sea. The total storage volume is about 1.5

million $m^3$. PFA is transferred from the power station, in the form of a slurry of about 30% PFA in seawater, by means of a pipeline several kilometres long. After sedimentation of the slurry by settlement of the ash component in the lagoons, the seawater portion is pumped back to the power station where it is discharged for disposal in the large body of open water at that location. The use of this facility started with delivery of ash slurry to the West Lagoon on 5 March 1987.

A programme of environmental monitoring of six metals (Cd, Cu, Pb, Zn, As and Se) in the seawater inside the three Tsang Tsui Ash Lagoons was carried out by CLP. The monitoring period covers the final eight months of the Stage I filling of the West Lagoon and the first two months of the Middle Lagoon. Duplicate samples were taken at monthly intervals from each of the three lagoons. For comparison, similar samples were also taken at a site just outside the lagoon wall and at several locations from the power station to Deep Bay where CLP have experimental oyster buoys and farms established as part of a related environmental project.

The test results are summarized in Table 9 against permissible concentration in "Draft Interim Effluent Guidelines" (EPD, 1984). It was concluded that the monitoring programme represented one of the more exact assessments of aqueous effluents from PFA, by virtue of the fact that very high ash to water ratios were used in the lagoon filling process. The work had identified a significant rise in the content of only one of the six metals of interest (selenium). It was difficult to interpret these findings in terms of local standards of acceptability because the EDP did not include selenium in their guidelines.

The monitoring data also indicated the effectiveness of the impermeable membrane material which was incorporated into the main seawall separating the lagoons from Deep Bay.

## 4.6 Tuen Mun New Town Area 47S PFA Reclamation

The site was reclaimed from marshy land and stream bed using conditioned PFA from Castle Peak Power Station (Figure 4). The area formed part of a reclamation which located between Lung Mun Road and the sea at Pillar Point, to the west of Tuen Mun. The land side of the seawall was lined with geo-synthetics to separate PFA particles from the sea. The laying of PFA was started on 20 March 1988 and was completed three months later on 27 June 1988. Environmental monitoring with respect to airborne dust and trace metal concentration in seawater were carried out by CLP during the period between 2 October 1987 and 21 July 1988 (viz. before, during and after reclamation).

Three sampling points were established, designated A, B and C (Figure 4). Point A was located immediately adjacent to the PFA reclamation site. The monthly sampling frequency was adopted to allow for collection of five duplicate samples before project commencement (for background data) and four samples during the site work. Concentration of Cd, Cu, Pb, Zn and Se were determined during the monitoring programme. The results for As were not presented in this report because of the use of an inappropriate test method. The test results are summarized in Table 10.

Test results indicated that the background level of trace metal in the general area is very variable. It was concluded in the report (CLP, 1991) that no elevated concentration of

the five trace metals were identifiable in the adjoining seawater above what have been shown to be very variable background concentration levels in the general area.

## 5. PROPOSED ENVIRONMENTAL CONTROL AND MONITORING

A set of general guidelines on environmental control and monitoring required for the use of fresh PFA under water is proposed in this report. This includes measures which could be used to mitigate unfavourable environmental effects arising from the handling of fresh PFA and its placement below sea level as well as details of the nature and scope of programme of monitoring of air and water qualities. These were based on the scheme adopted for the Urmston Road project. The guidelines indicate the scope of works involved in a typical project in Hong Kong. The proposed environmental control and monitoring guidelines are given in Appendices B and C. Part of the proposed guidelines has been reviewed by the EPD.

In these proposed guidelines, air monitoring will continue during construction only, while water monitoring is required up to 3 years, at 3 months, 6 month and every 6 months afterwards, after the start of project. However the need for the last two years of monitoring will be assessed by the EPD at the end of the first year after PFA placement and environmental monitoring can be terminated if the EPD consider that the results are conclusive at that stage.

Based on the above proposed guidelines and the cost in early 1994, it is estimated that the water monitoring requirements and the environmental specialist input would cost at the minimum HK$300,000. The actual cost has to be assessed on a site specific basis.

## 6. DISCUSSION

The main reason for the EPD requirements seems to be insufficient data on possible impact of leachate from fresh PFA on marine life. The conservative position has been taken that, if it has not been demonstrated that the material is adequately safe, it should not be allowed to be used generally.

The need for these requirements should be assessed in the light of the real necessity as well as the level of resources to be expended to meet them. While there are much positive data from laboratory and field tests for use of PFA in various conditions, only a small proportion of these data refer directly to the use of fresh PFA under water. Therefore, there is some validity in the argument of insufficient data.

The attractiveness of the use of PFA is its low cost, particularly at sites near power stations. Therefore if the project owner can realise sufficient financial gain in excess of the cost required for environmental work, he would be quite willing to proceed with the work. This has been demonstrated by the project at Urmston Road, in which the contractor chose PFA as fill material in spite of environmental control and monitoring requirements similar to those proposed in Appendices B and C.

The user is reluctant to use PFA if the scope and details of environmental work are

not clear. However if the requirements are accurately known, the user may be willing to pay the cost but may not welcome the need for long term monitoring commitment. This could be resolved by engaging an environmental specialist firm to undertake and report on long term monitoring to EPD.

In the study carried out by SWK and Aspinwall in 1991 (CLP 1991), the test method for the PFA leaching trials was based on a method established in the UK in 1982. This method was designed for the assessment of long-term leaching behaviour of wastes disposed in a landfill. This method may not be able to reflect the actual leaching behaviour of using PFA for reclamation. A more appropriate method should be developed for future studies.

As no relevant standard or guidelines are available, the EPD's "Technical Memorandum on Standards for Effluents Discharged into Drainage and Sewerage Systems, Inland and Coastal Waters" was used to assess the use of PFA as fill material for reclamation. This standard was principally designed as guidance for issuing effluent discharge licences. This may not be a relevant standard to assess the environmental impact of using PFA for reclamation. As an approximate indication, when comparing the leached metal contents of fresh PFA determined in SENT project with the Ontario Lakefilling Guidelines, the fresh PFA satisfies the requirements for material to be filled in confined area.

## 7. CONCLUSIONS

Apart from the Urmston Road projects there has been no other case of fresh PFA placed under water. Monitoring of the Urmston Road project was incomplete and inconlusive. The leachate trials carried out between March 1990 and March 1991 for the Lamma Quarry Restoration project, although extensive, addressed the use of fresh PFA in landfill but not in marine reclamation. Likewise other studies and trials previously carried out in Hong Kong, although providing useful information for reference, were not completely relevant to the use of fresh PFA under water.

EPD's insistence upon treating the use of fresh PFA as reclamation material on a case-by-case basis is, therefore, not unreasonable. After all, the level of allowable contaminants varies in different parts of the coastal waters; the EPD's Technical Memorandum on Effluent Discharge states different criteria for different areas. In addition, it is already well known that the concentration of toxic metals are likely to vary from one PFA type to another. However, the EDP is prepared to review specific proposals for "suitable field trials". The 3-year requirement for post reclamation monitoring is an arbitrary length of time and they are prepared to review the requirement after seeing the results of the first year after completion of trial filling. It should be noted that the resources spent in such environmental works will be very worthwhile if at the end the issue of environmental impacts can be conclusively resolved.

A set of environmental guidelines has been proposed herein on the basis of the scheme used for Urmston Road project, including a monitoring scheme to provide the needed field data. It is also suggested that some simple laboratory tests on fresh PFA samples itself may be used to verify the suitability of a PFA for marine filling with suitable acceptance criteria, on a similar basis to that used for lake fill material in Canada. In due course, such tests could be used to supplement and finally replace the time-consuming monitoring requirements.

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## LIST OF TABLES

Table 1 - Summary of Recent Projects Using PFA from CLP

| Project | Quantity | Use of PFA |
|---|---|---|
| Tuen Mun New Town Area 2A, Public Dump | 44,000 $m^3$ | Fresh PFA disposal in a public dump on land. |
| Tuen Mun New Town Area 2A, Roads D7 and LD6 | 35,000 $m^3$ | Site formation and road embankment. Lagooned PFA leached for less than 2 years. |
| Tuen Mun New Town Area 2A, Road P2 (D4 to D7) and Interchange P2/D4 | 28,000 $m^3$ | Road embankment. Lagooned PFA leached for less than 2 years. |
| Tuen Mun New Town Area 7, Roads D6 and LD3 West | 110,000 $m^3$ | Site formation and road embankment. Lagooned PFA leached for less than 2 years. |
| Tuen Mun New Town Area 16S, Reclamation Areas 14 and 16S | 50,000 $m^3$ | Above water reclamation. Lagooned PFA leached for less than 2 years. |
| Eastern Harbour Crossing | 15,000 $m^3$ | Marine reclamation. Lagooned PFA leached for less than 2 years. |
| Siu Lang Shui Ash Disposal | 320,000 $m^3$ | PFA landfill project. Fresh PFA. |
| Tsang Tsui Ash Lagoons | 1,500,000 $m^3$ | Storage lagoons. Fresh PFA. |
| Tuen Mun Area 47S Reclamation | 50,000 $m^3$ | Reclamation of marsh. Lagooned PFA leached for less than 2 years. |
| Urmston Road Outfall | 250,000 $m^3$ | Marine reclamation. Fresh PFA. |
| New Territories (6 projects) | 230,000 $m^3$ | Reclamation of marsh and fish pond areas. Lagooned PFA leached for less than 2 years. |

Table 2 - Chemical Composition of PFA from Various Sources (after CLP 1990)

| Constituent | | Percentage by Weight | | | | | |
|---|---|---|---|---|---|---|---|
| | | Castle Peak | | | United Kingdom | South Africa | USA |
| | | Min. | Max. | Ave. | | | |
| Silicon | ($SiO_2$) | 38 | 77 | 54 | 41 - 49 | 50 | 30 - 58 |
| Aluminium | ($Al_2O_3$) | 14 | 46 | 29 | 22 - 29 | 30 | 7 - 38 |
| Iron | ($Fe_2O_3$) | 1.2 | 18 | 4.8 | 7 - 12 | 4 | 10 - 42 |
| Calcium | (CaO) | 0.01 | 15.6 | 4.8 | 1.2 - 6.8 | 5.2 | 0 - 13 |
| Magnesium | (MgO) | 0.02 | 2.6 | 1.0 | 1.2 - 2.3 | 1.0 | 0 - 3 |
| Potassium | ($K_2O$) | 0.13 | 2.4 | 0.9 | nr | nr | 0.4 |
| Sodium | ($Na_2O$) | 0.03 | 1.8 | 0.4 | nr | 1.2 | |
| Titanium | ($TiO_2$) | 0.5 | 2.4 | 1.4 | 0.8 - 1.0 | nr | nr |
| Sulphur | ($SO_3$) | 0.06 | 0.75 | 0.6 | 0.6 - 1.8 | 0.6 | 0.2 |
| Loss on Ignition | | 3.6 | 8.0 | 5.7 | 0.6 - 6.5 | 5.5 | 0 - 48 |

Note : nr denotes not reported.

Table 3 - Trace Element Concentration in PFA from Castle Peak and Other Sources (after CLP 1990)

| Trace Element | | Castle Peak | USA | | | United Kingdom | |
|---|---|---|---|---|---|---|---|
| | | | East | West | Mid | Source A | Source B |
| Arsenic | (As) | 11 - 89 | 159 | 119 | 73 | 110 | 80 |
| Cadmium | (Cd) | 0.1 - 0.8 | nr | nr | nr | 5 | 6 |
| Chromium | (Cr) | 19 - 113 | 230 | 224 | 66 | 120 | 120 |
| Copper | (Cu) | 56 | 128 | 89 | 47 | 210 | 160 |
| Lead | (Pb) | 4 - 47 | 55 | 131 | 29 | 110 | 90 |
| Selenium | (Se) | 2 - 7 | nr | nr | nr | 5 | 90 |
| Zinc | (Zn) | 122 | 230 | 743 | 258 | 130 | 90 |
| Boron | (B) | nr | 265 | 731 | 258 | 210 | 170 |

Notes: (1) All figures in ppm of dry PFA.
(2) nr denotes not reported.
(3) Concentration of other metals were not reported.

Table 4 - Permitted Limits of Metal in Sea Food

| Metal | Max. Concentration (ppm wet weight) |
|---|---|
| Antimony | 1.0 |
| Arsenic | 6[(1)] or 10[(2)] |
| Cadmium | 2.0 |
| Chromium | 1.0 |
| Lead | 6.0 |
| Mercury | 0.5 |
| Tin | 230 |

Notes: (1) 6 ppm is the maximum level for seafood.
(2) 10 ppm is the maximum level for shellfish.
(3) This table extracted from Food Adulteration (Metallic Contamination) Regulation 1993.

Table 5 - Guideline Values for Health-related Inorganic Constituents in Drinking Water (after WHO 1984)

| Constituent | Guideline Value (mg/litre, ppm) |
|---|---|
| Arsenic (As) | 0.05 |
| Cadmium (Cd) | 0.005 |
| Chromium (Cr) | 0.05 |
| Cyanide | 0.1 |
| Fluoride (F) | 1.5 |
| Lead (Pb) | 0.05 |
| Mercury (Hg) | 0.001 |
| Nitrate (as N) | 10.00 |
| Selenium (Se) | 0.01 |

Table 6 - Interim Confined Fill Guidelines Mandatory Parameter List

| Parameter | | Guidelines ($\mu$g/g, ppm, unless otherwise stated) |
|---|---|---|
| Antimony | Sb | 0.43 |
| Arsenic | As | 11 |
| Barium | Ba | 160 |
| Beryllium | Be | 1.1 |
| Cadmium | Cd | 0.7 |
| Chromium VI | Cr | 1 |
| Chromium (total) | Cr | 58 |
| Cobalt | Co | 16 |
| Copper | Cu | 41 |
| Lead | Pb | 45 |
| Mercury | Hg | 0.2 |
| Molybdenum | Mo | 1 |
| Nickel | Ni | 38 |
| Selenium | Se | 0.93 |
| Silver | Ag | 0.27 |
| Vanadium | V | 77 |
| Zinc | Zn | 120 |
| Electrical Conductivity | | 0.36 (S/m) |
| Sodium Absorption Ratio | SAR | 0.7 (dimensionless) |
| pH | | 3-10 (dimensionless) |

Note : These interim guidelines are extracted from the Proposed Policy for Management of Excess Soil, Rock and Like Materials, Ministry of Environment and Energy, Ontario, Canada, May 1992 (draft) and define the upper limits of materials that can be used in a lakefill.

Table 7 - Results of Total Metal Analyses Undertaken on Solid PFA Samples SENT Landfill Trial Test (after CLP 1991)

| Type of PFA | Concentration (mg/l) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cd | Cr | As | Pb | Hg | Cu | Ni | Zn | Fe | Mn | Al | Se |
| Fresh PFA | <1 | 30 | 10 | 16 | <1 | 22 | 30 | 46 | 46600 | 210 | 220 | <1 |
| Lagooned PFA | <1 | 62 | 12 | 6 | <1 | 24 | 28 | 30 | 28660 | 182 | 257 | <1 |

Table 8 - Standards for Effluents Discharged into the Marine Waters of Southern Mirs Bay, Junk Bay, North Western, Eastern Buffer and Western Buffer Water Control Zones (EPD, 1991)

| Determinand | Upper Limits (mg/l) for Effluents Discharge at Various Flow Rate ($m^3$/day) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ≤10 | >10 and ≤200 | >200 and ≤400 | >400 and ≤600 | >600 and ≤800 | >800 and ≤1000 | >1000 and ≤1500 | >1500 and ≤2000 | >2000 and ≤3000 | >3000 and ≤4000 | >4000 and ≤5000 | >5000 and ≤6000 |
| pH (pH units) | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 | 6-10 |
| Temperature (°C) | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 |
| Colour (lovibond units) (25 mm cell length) | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Suspended solids | 500 | 500 | 500 | 300 | 200 | 200 | 100 | 100 | 50 | 50 | 40 | 30 |
| BOD | 500 | 500 | 500 | 300 | 200 | 200 | 100 | 100 | 50 | 50 | 40 | 30 |
| COD | 1000 | 1000 | 1000 | 700 | 500 | 400 | 300 | 200 | 150 | 100 | 80 | 80 |
| Oil & grease | 50 | 50 | 50 | 30 | 25 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Iron | 20 | 15 | 13 | 10 | 7 | 6 | 4 | 3 | 2 | 1.5 | 1.2 | 1 |
| Boron | 6 | 5 | 4 | 3.5 | 2.5 | 2 | 1.5 | 1 | 0.7 | 0.5 | 0.4 | 0.3 |
| Barium | 6 | 5 | 4 | 3.5 | 2.5 | 2 | 1.5 | 1 | 0.7 | 0.5 | 0.4 | 0.3 |
| Mercury | 0.1 | 0.1 | 0.1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Cadmium | 0.1 | 0.1 | 0.1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Other toxic metals individually | 2 | 1.5 | 1.2 | 0.8 | 0.6 | 0.5 | 0.32 | 0.24 | 0.16 | 0.12 | 0.1 | 0.1 |
| Total toxic metals | 4 | 3 | 2.4 | 1.6 | 1.2 | 1 | 0.64 | 0.48 | 0.32 | 0.24 | 0.2 | 0.14 |
| Cyanide | 1 | 0.5 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.15 | 0.1 | 0.08 | 0.06 | 0.04 |
| Phenols | 0.5 | 0.5 | 0.5 | 0.3 | 0.25 | 0.2 | 0.13 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Sulphide | 5 | 5 | 5 | 5 | 5 | 5 | 2.5 | 2.5 | 1.5 | 1 | 1 | 0.5 |
| Total residual chlorine | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Total nitrogen | 100 | 100 | 80 | 80 | 80 | 80 | 50 | 50 | 50 | 50 | 50 | 50 |
| Total phosphorus | 10 | 10 | 8 | 8 | 8 | 8 | 5 | 5 | 5 | 5 | 5 | 5 |
| Surfactants (total) | 30 | 20 | 20 | 20 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| E. Coli (count/100 ml) | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 |

Note : All units in mg/l unless otherwise stated; all figures are upper limits unless otherwise indicated.

Table 9 - Summary of Monitoring Results for the West Lagoon, Tsang Tsui Ash Lagoons Project (after CLP 1989b)

| Location | Average Total Recoverable Metals (ppb) | | | | | |
|---|---|---|---|---|---|---|
| | Cd | Cu | Pb | Zn | As | Se |
| West Lagoon | 0.16 | 3.5 | 2.5 | 15 | 5 | 360 |
| Just outside lagoon seawall | 0.09 | 3.6 | 2.3 | 7 | < DL | < DL |
| CLP oyster buoys and farms | < DL | 2.1 | 1.0 | 23 | < DL | no data |
| EPD effluent guidelines | 100 | 2000 | 2000 | 2000 | 2000 | not given |
| Note : (< DL) : Value of test result less than the detection limit of the analysis method. | | | | | | |

Table 10 - Summary of Trace Metal Monitoring Test Results, Tuen Mun New Town Area 47S PFA Reclamation (after CLP 1989a)

| Location | Average Total Recoverable Metals Before and During Reclamation (ppb) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cd | | Cu | | Pb | | Zn | |
| | Before | During | Before | During | Before | During | Before | During |
| Point A | 0.28 | 0.18 | 5.0 | 4.3 | 3.7 | 8.8 | 28 | 16 |
| Point B | 0.11 | 0.21 | 6.9 | 2.2 | 2.9 | 4.4 | 15 | 17 |
| Point C | 0.12 | 0.17 | 7.1 | 2.4 | 2.7 | 5.9 | 18 | 5 |
| Note : Background level of trace metals in seawater in the area is very variable. | | | | | | | | |

## LIST OF FIGURES

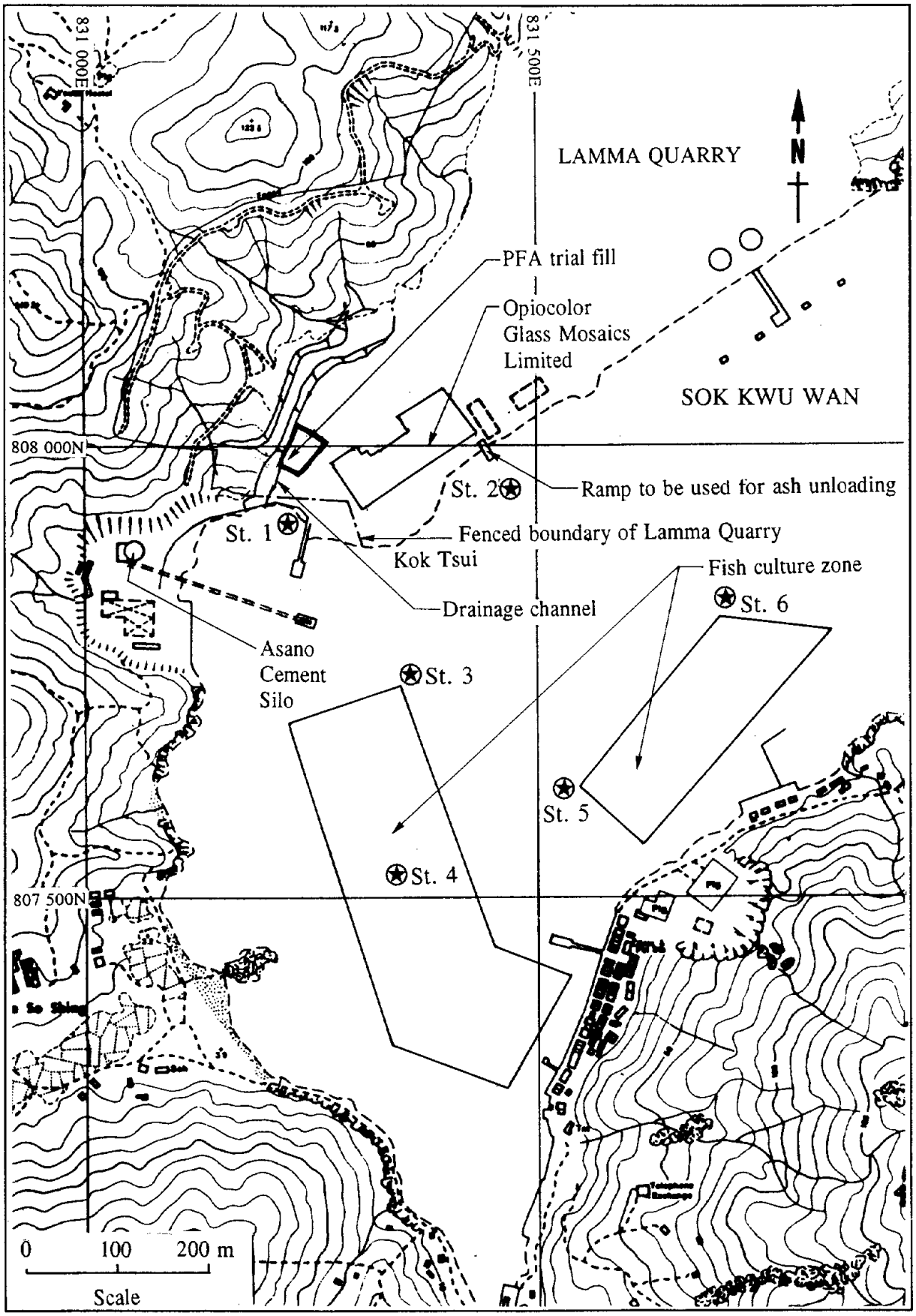


Figure 1 - Lamma Quarry Restoration, Sampling Locations for Marine Monitoring

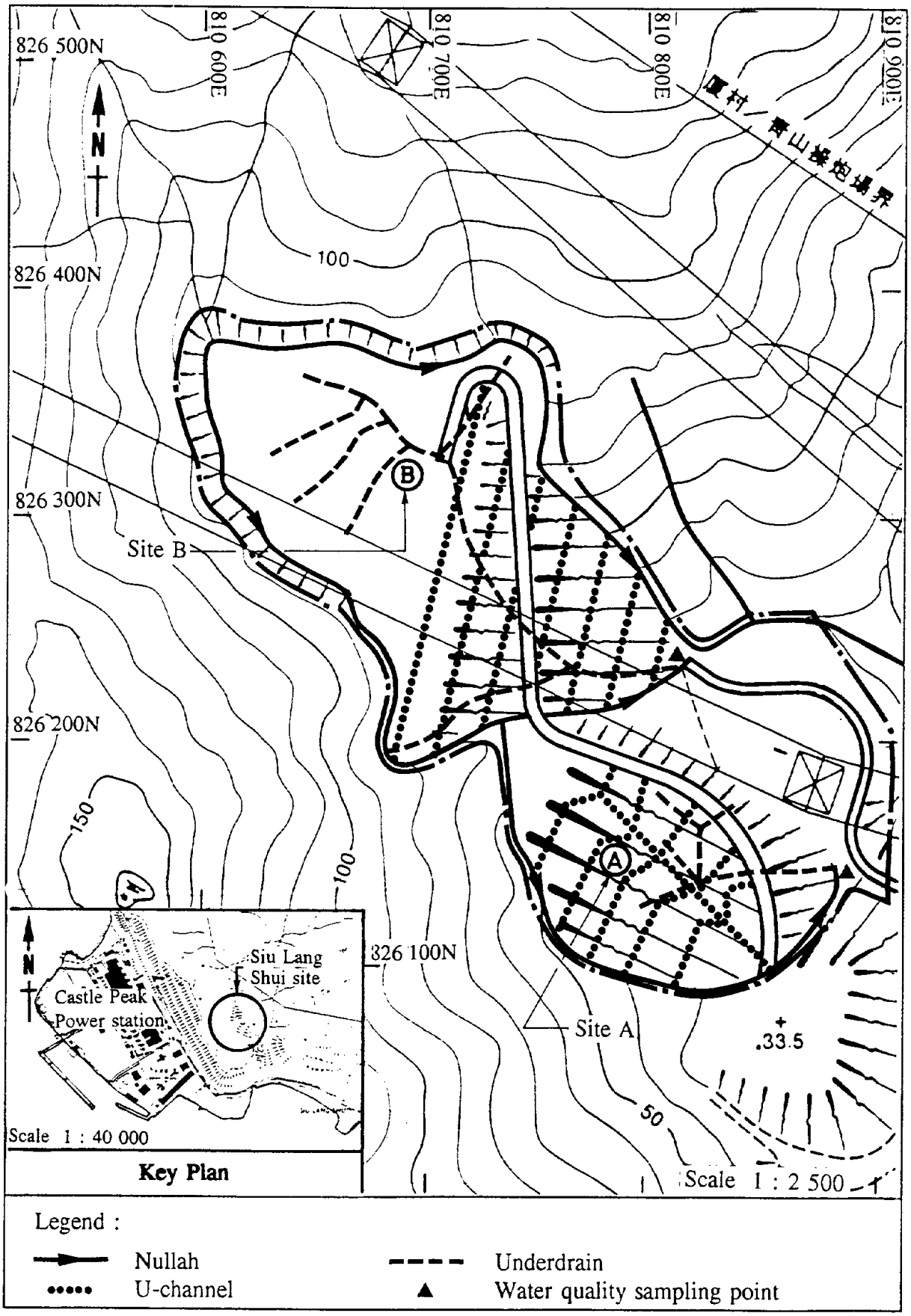


Figure 2 - Layout of Underdrain at Siu Lang Shui Site

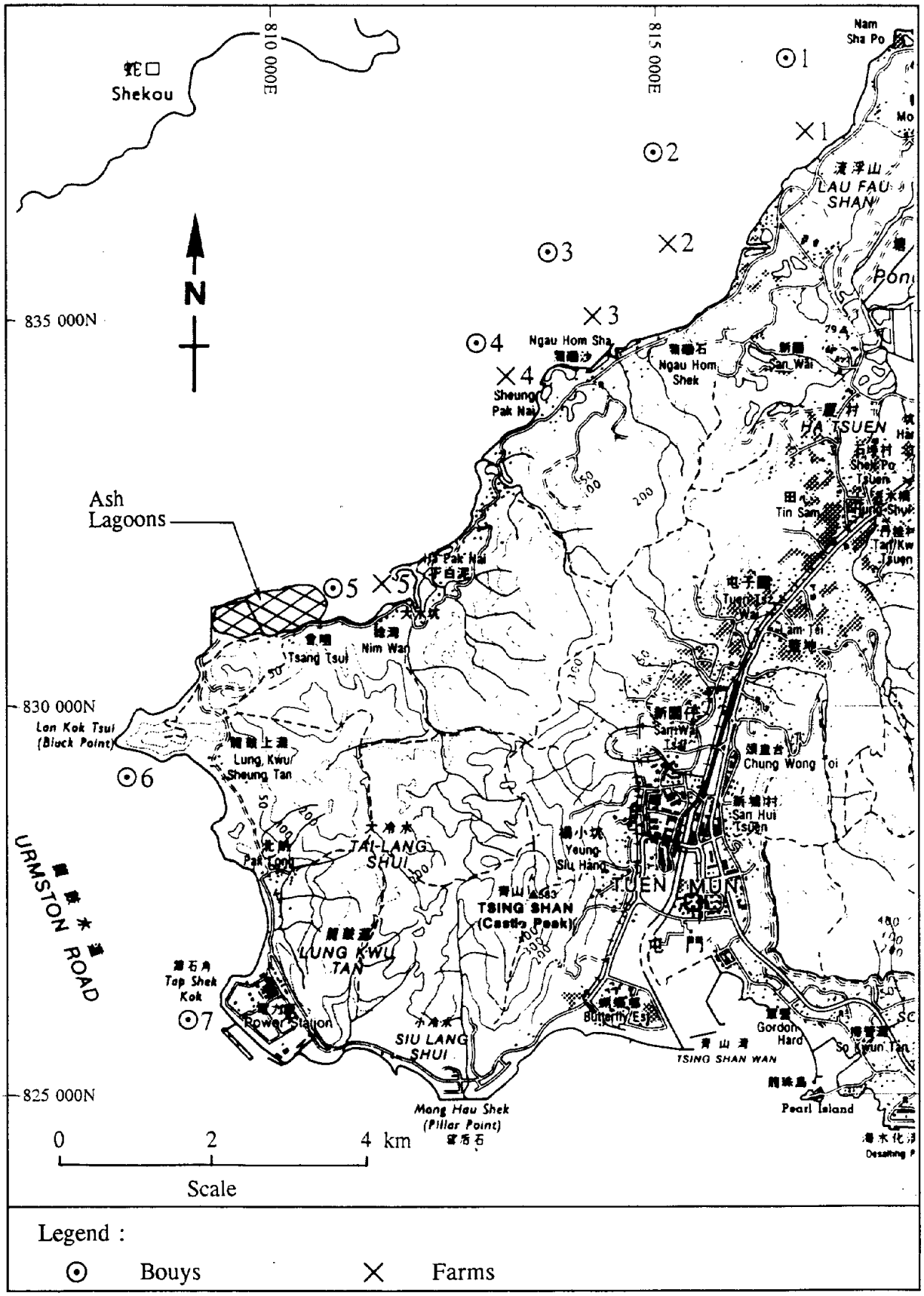


Figure 3 - Tsang Tsui Ash Lagoons, Location of CLP, Experimental Oyster Bouys and Farms in Deep Bay

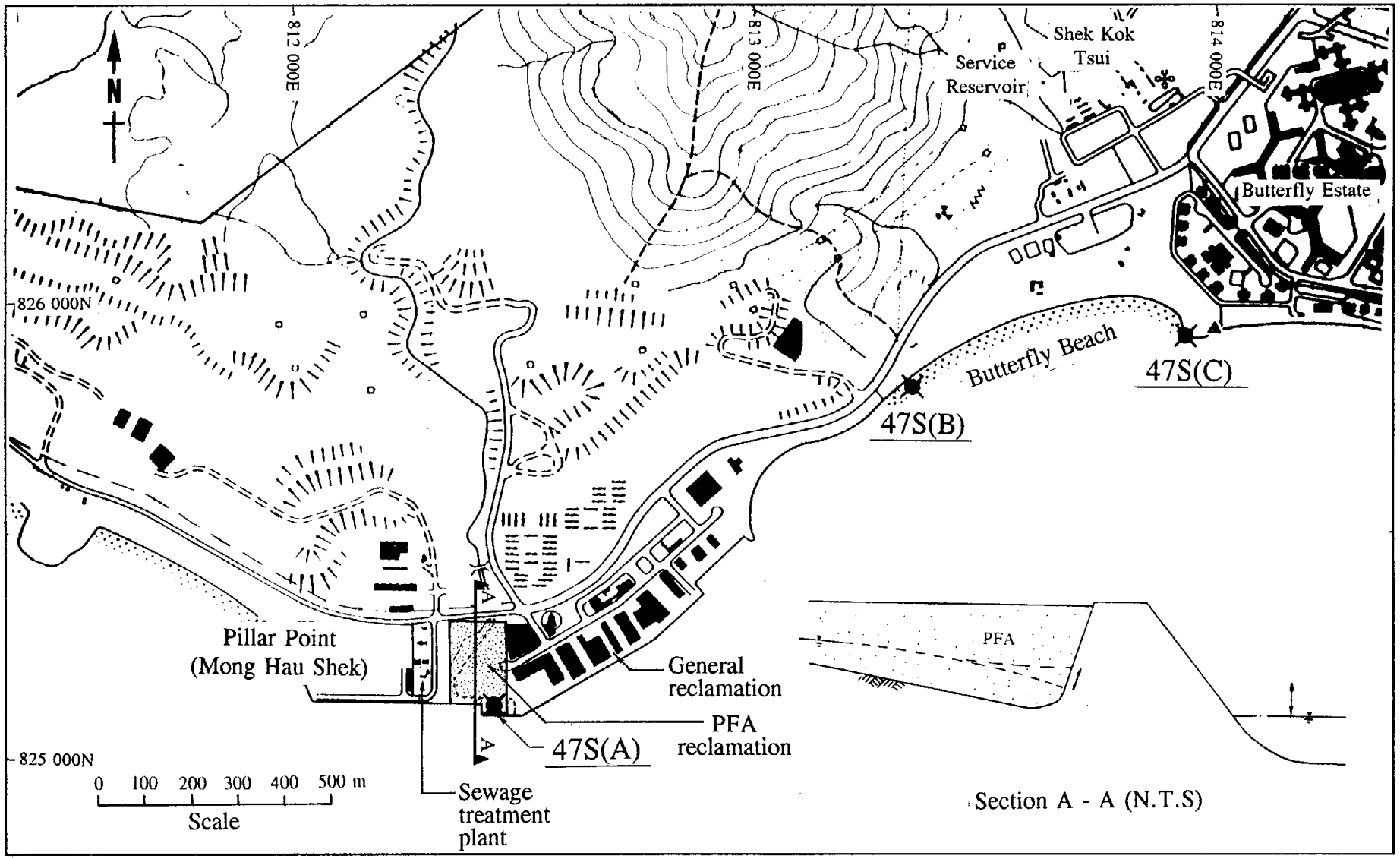


Figure 4 - Location Map of Tuen Mun New Town Area 47S

# APPENDIX A

## WORKS BRANCH TECHNICAL CIRCULAR No. 14/94
## USE OF PFA AS GENERAL FILL IN RECLAMATIONS

Ref : WB(W) 209/32/31

WORKS BRANCH
GOVERNMENT SECRETARIAT
MURRAY BUILDING
GARDEN ROAD
HONG KONG

22 July 1994

Works Branch Technical Circular No. 14/94

Use of PFA as General Fill in Reclamations

## Introduction

This Circular explains the procedure for using Pulverised Fuel Ash (PFA) as general fill in reclamations, both above and below water, and it gives guidelines for its use. The Circular also outlines the role of the Fill Management Committee (FMC) in co-ordinating the use of PFA as fill material.

2. The contents of this Circular have been agreed with the Secretary for Planning, Environment & Lands. It should be brought to the attention of all consultants and contractors engaged on Government and quasi-Government projects, and on major private projects which require fill material.

## Background

3. The power companies in Hong Kong currently produce about one million tonnes of PFA per annum, of which approximately half is stored in purpose-built ash lagoons. The other half is disposed of either outside Hong Kong or as general fill material in Hong Kong in land formation above water and as a raw material in cement manufacture.

4. A technical review by the Civil Engineering Department concluded that PFA should be considered in a similar manner to other reclamation fill materials commonly used in Hong Kong, and its suitability for use in any particular application should be assessed based on its engineering properties.

## Use of *Lagooned PFA*

5. Lagooned PFA refers to PFA which has been stored in a lagoon. Provided suitable operational procedures are adopted, the Environmental Protection Department (EPD) has no objection to the use of PFA from the lagoons ('lagooned' or 'leached' PFA) as general reclamation fill both above and below water, if it has been lagooned for not less than two years, and except in areas which are particularly environmentally sensitive. After further experience of the use of PFA, it may be possible to reduce the two-year requirement for use below water in future.

6. Prior to the use of lagooned PFA in any marine reclamation, the Environmental Protection Department should be contacted regarding the proposed location. The procedures for Environmental Review detailed in Planning, Environment & Lands Branch Technical Circular No. 2/92 (same as WBTC 14/92) shall be followed where applicable. When the lagooned PFA is transported by sea and placed in a reclamation site, suitable measures shall be adopted in order to minimise the release of PFA into the open sea and into the air as dust. For example, it may be necessary to place the PFA by pumping in slurry form over a completed seawall, or to construct a seawall with a geotextile liner.

7. When the lagooned PFA is transported by road or when it is placed above water, operational procedures shall be as laid down in paragraph 11 below.

Use of *Fresh PFA*

8. Newly-produced PFA ('fresh' PFA) shall not be used as fill below water until its environmental acceptability has been demonstrated by suitable field trials. Until such time, the acceptability of using fresh PFA as fill below water will be assessed by EPD on a case-by-case basis. Currently, fresh PFA is acceptable for use as fill above water for land formation, provided the air pollution control measures outlined in paragraph 11 are followed.

Availability of PFA

9. Subject to availability, Hong Kong Electric Company (HEC) has agreed to make available fresh, and in a few years hence, lagooned PFA as fill, loaded into contractors' barges at the HEC plant, free of charge. Subject to availability, China Light & Power (CLP) has also agreed to make available fresh PFA as fill, loaded into contractors' barges or trucks at the CLP plant, free of charge. Subject to availability, CLP has additionally agreed to make available lagooned PFA, but there may be a cost for its extraction and loading into barges. Detailed arrangements will need to be worked out between the Companies concerned and the users for specific projects.

Role of the FMC

10. The FMC, as the authority for the allocation of fill sources to reclamation projects, may require Government Departments to include PFA as reclamation fill, both above and below water, where this is considered by the FMC to be feasible. When a project is required to include PFA, the project department will be informed by the FMC if DEP requires any monitoring or special operational procedures beyond those detailed in paragraph 11.

Air Pollution Control Requirements

11. When lagooned or fresh PFA is transported by road or used as fill above water, dust suppression measures shall be implemented at all times to prevent dust nuisance. These measures shall include, but shall not be limited to, the measures listed in Appendix A.

**Information on PFA**

12. For every project where PFA is used as fill, the information on the proforma at Appendix B should be forwarded to the Secretary FMC, Civil Engineering Department once filling has been completed.

13. Enquiries regarding this Circular should be addressed to the Secretary FMC, Civil Engineering Department.

( P J Berry )
**Deputy Secretary (Works Branch) (Ag)**

**Appendix A**
of WBTC 14/94

## AIR POLLUTION CONTROL REQUIREMENTS FOR THE TRANSPORTATION AND HANDLING OF PFA

When lagooned or fresh PFA is transported by road or used as fill above water, dust suppression measures shall be implemented at all times to prevent dust nuisance, and these shall include, but not be limited to, the following measures :

(1) In the process of loading and handling, PFA which has the potential to create dust shall be treated with water or sprayed with a wetting agent.

(2) PFA shall be transported either wet or damp ('conditioned') and covered, or in sealed containers. PFA shall be placed and compacted the same day it arrives on site and shall not be stockpiled.

(3) The site shall be frequently cleaned and watered to minimise fugitive dust emission.

(4) Any vehicle with an open load-carrying area used for moving PFA which has the potential to create dust shall have properly-fitting side and tail boards. PFA with the potential to create dust shall not be loaded to a level higher than the side and tail boards, and shall be covered by a clean tarpaulin. The tarpaulin shall be properly secured and shall extend at least 300mm over the edges of the side and tail boards.

(5) All motorized vehicles shall be restricted to a maximum speed of 8km per hour within the site. Haulage and delivery vehicles shall be confined to designated roadways inside the site. Areas of roadway longer than 100 m on which the movement of motorized vehicles exceeds 100 vehicle movements per day, or as directed by the Engineer, shall be finished with a flexible pavement surfacing. The road pavement design shall be to "Guidance Notes on Pavement Design (RD/GN/017)" issued by the Highways Department and its amendments as stipulated in Highways Departments Technical Circular No. 5/93, or to a standard as agreed by the Engineer.

(6) Wheel washing facilities shall be installed and used by all vehicles leaving the site. No PFA whatever shall be deposited on public roads. Water in the wheel-washing facility shall be changed at frequent intervals, and sediment shall be removed regularly. The wheel-washing facility shall be operational prior to any earthwork activities on the site. The contractor shall provide a hard-surfaced road between the wheel-washing facilitate and the public road.

(7) The PFA filling including final compaction shall be completed, as quickly as possible, to minimise wind-blown dust.

(8) A final cover layer of natural soil, with a minimum thickness of 1 metre, shall be provided to areas where PFA has been used as a fill material.

**Appendix B**
of WBTC 14/94

To : Secretary, Fill Management Committee
Geotechnical Engineering Office
Civil Engineering Department
13/F Civil Engineering Building
101 Princess Margaret Road
Ho Man Tin, Kowloon
Tel : 762 5397 Fax : 714 0072

## INFORMATION ON PFA FILLING WORKS

Department/Division/Office :

Project/Contract Name and Location:

Contract No. :

Type of PFA used : fresh/lagooned/both

Type of use : above/below water/both

Quantity of fresh PFA ($m^3$) :

Quantity of lagooned PFA ($m^3$) :

Commencement and completion dates of PFA filling :

Record of any problems encountered with the use of PFA as fill :

Location plan of the PFA fill area is attached

Signed.....Date.....

Name & Post.....

Telephone No.....

# APPENDIX B

# PROPOSED GUIDELINES FOR ENVIRONMENTAL CONTROL AND MONITORING

This appendix should be read in conjunction with WBTC 14/94. The following are the proposed guidelines for environmental control and monitoring.

## B.1 AIR POLLUTION CONTROL REQUIREMENTS

The following dust suppression measures shall be implemented at all times to prevent dust nuisance as a result of site activity or as directed by the Engineer's Representative :

(a) In the process of material loading and handling, any material which has the potential to create dust shall be treated with water or sprayed with wetting agent.

(b) Stockpile of sand and aggregate greater than 20 $m^3$ shall be enclosed on three sides, with walls extending above the pile and 2 metres beyond the front of the pile. In addition, an effective water spray shall be provided and used both to dampen stored materials and during reception of raw materials.

(c) The Site shall be frequently cleaned and watered to minimise fugitive dust emission.

(d) All motorized vehicles shall be restricted to a maximum speed of 8km per hour within the site. Haulage and delivery vehicle shall be confined to designated roadways inside the site.

(e) Any vehicle with an open load carrying area used for moving fresh PFA shall have properly fitting side and tail boards and not be loaded to a level higher than the side and tails boards, and shall be dampened and covered by clean tarpaulin. The tarpaulin shall be properly secured and shall extend at least 300 mm over the edges of the side and tail boards.

(f) Areas of reclamation shall be completed, including final compaction, as quickly as possible, to minimise wind blown dust.

A cover layer consisting of natural soil with a thickness of not less than 1 metre shall be provided to areas of reclamation wherein the fresh PFA has been used as a fill material. The provision of wheel washing bays shall not be a mandatory requirement because some sites may be constrained. However, it must be ensured that vehicle wheels are properly cleaned by removing earth, mud, debris, dust and the like before allowing the vehicles to enter public roads. This requirement shall be reflected in the contract with the Contractor.

## B.2 WATER POLLUTION CONTROL REQUIREMENTS

The trial reclamation area shall be entirely enclosed by seawall before placing of fresh PFA. A geo-synthetic material, suitable to retain fresh PFA, shall be provided along the inside face of all seawalls which contain the fresh PFA. Care shall be taken when placing the fresh PFA to ensure that there is no spillage into the open sea.

## B.3 AIR MONITORING PROPOSAL

At least two high volume air sampler and associated equipment shall be provided and operated in accordance with the USA Standard Title 40 Code of Federal Regulations, Chapter 1 (part 50) Appendices B and J, or equivalent. Sampling shall be carried out one day in every six days at ten number sampling points on the site boundary for such periods and in a manner as instructed by the Engineer. The samplers and equipment shall be constructed so as to be transferable between sampling points to enable monitoring of total suspended particulate matter and respirable suspended particulate matter in air at any sampling point required by the Engineer. All necessary protection fences and the like shall be provided at sampling points. Testing and analysis of sampled materials shall be carried out by a laboratory approved by the Engineer.

Air monitoring will be carried out during the placement of fresh PFA placing only.

## B.4 WATER MONITORING PROPOSALS

Prior to the commencement of the works, specific sampling stations in the open sea shall be proposed for approval by the EPD. These locations shall then be specified under the Contract. Samples can be taken inside the seawall or at piezometric wells on land if so directed by the Engineer's Representative. Oyster, or other suitable bio-indicators of heavy metal pollution, shall be used as a means of biomonitoring. The species to be tested, their quantities and locations shall be agreed with the EPD.

The tests shown in Appendix B shall be carried out by an approved laboratory. Seawater, marine sediment and oyster tissue samples shall be taken after placing of fresh PFA or at such times as required by the EPD. In total, no more than five sets of samples will be required for the first twelve months after commencement of reclamation. Samples shall be taken at three months, six months and twelve months after placing of fresh PFA. The EPD may require groundwater samples to be taken at piezometric wells installed at appropriate locations on land for analysis; the details of which will be similar to the analysis of seawater samples shown in Appendix C.

All of the above sampling and testing shall be carried out for a period of three years, at 6-month intervals for the last two years. However, the EPD shall assess the test results at 12 months after the placing of fresh PFA and shall permit termination of monitoring if the results prove conclusively the effects of the placement of fresh PFA. The findings are intended to provide a scientific basis for setting appropriate requirements for the use of fresh PFA in reclamation below the water level.

The criteria for assessing the results of the above tests shall be based on the baseline values established at each test location and for each type of test, prior to placing of the fresh PFA.

## B.5 SPECIALIST INPUT

The trial study, including sampling locations, selection of organisms for biological monitoring, collection of samples, analysis and interpretation of results shall be supervised and coordinated by an environmental specialist, who is also responsible for the submission of results for assessment by the EPD.

# APPENDIX C

## TESTING OF SEA WATER, MARINE SEDIMENTS AND OYSTER TISSUE SAMPLES

## C.1 TESTING OF SEA WATER SAMPLES

(a) Physical parameters

- Water depth of sampling station: *measured by echo-sounder*
- Temperature: *measured by the temperature probe of the Dissolved Oxygen (DO) meter*
- Dissolved oxygen: *a submersible DO probe equipped with a stirrer is lowered to the appropriate depth and the DO content is measured in situ*
- Salinity: *measured by conductivity meter*
- Turbidity: *measured by turbidimeter*
- pH: *measured by pH meter*

(b) Chemical parameters

- Biochemical Oxygen Demand: *measured by dissolved oxygen meter before and after incubation at 20°C for 5 days*
- Chemical Oxygen Demand: *open reflux with potassium dichromate and mercuric sulphate followed by titrimetric determination*

(c) Heavy metals ($\mu$g/litre level)

- Arsenic, Mercury and Selenium: *acid digestion followed by atomic adsorption spectrophotometer measurement with hydride generator*
- Boron: *colorimetric determination by using Carmine Method*
- Cadmium, Chromium, Copper, Lead and Nickel: *acid digestion followed by graphite furnace atomic adsorption spectrophotometer measurement with Zeeman background correction*
- Zinc: *chelation extraction reference ASTM D1691 followed by atomic adsorption spectrophotometer measurement*

*(The accuracy of measurement required for Cadmium and Mercury is $\pm$0.1 mg/litre. For the other metals, the required accuracy of measurement is $\pm$1.0 mg/litre.)*

## C.2 TESTING OF MARINE SEDIMENTS

(a) Particle size distribution: *reference to BS1377:1990*

(b) Heavy metals (mg/kg level)

- Arsenic, Mercury and Selenium: *acid digestion followed by atomic adsorption spectrophotometer measurement with hydride generator*

- Boron (water soluble): *water extraction followed by colorimetric determination using Carmine method*

- Cadmium, Chromium, Copper, Lead, Nickel and Zinc: *acid digestion followed by atomic adsorption spectrophotometer measurement*

*(The accuracy of measurement required for Cadmium and Mercury is ±0.1 mg/kg. For the other metals, the required accuracy of measurement is ±1.0 mg/kg.)*

## C.3 TESTING OF OYSTER TISSUE SAMPLES

(a) Heavy metal content of oyster tissue (mg/kg level)

- Arsenic, Mercury and Selenium: *acid digestion and atomic absorption spectrometry vapour generation technique*

- Boron: *acid digestion and colorimetry*

- Cadmium, Chromium, Copper, Lead, Nickel and Zinc: *acid digestion and atomic absorption spectrometry*

*(The accuracy of measurement required for Mercury is ±0.1 mg/kg. For the other metals, the required accuracy of measurement is ±1.0 mg/kg.)*