GEOINVEST LTD **SWECO INTERNATIONAL**

Republic of Cyprus

Ministry of Agriculture, Natural Resources and Environment

Geological Survey Department

Study of the Askarel Disposal Site
Final Report

Stockholm May 26, 2003
SWECO International AB

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Preface and Acknowledgements

The present report presents the results and recommendations of the project “8/2000 Study of the Askarel Disposal Site”.

The study has been financed by the Republic of Cyprus, Ministry of Agriculture, Natural Resources and Environment and co-ordinated by the Geological Survey Department.

We wish to express our gratitude for the professional and friendly cooperation during pursuit of the project to the Director of Geological Survey Department Georg Petrides, and Dr. Antonis Charalambides, Head of Laboratory, and other staff members at GSD participating in the project.

Furthermore, as environmentalists we are happy to find that the situation at the site is satisfactory concerning the risks for spreading of PCBs, indicating that the actions taken by GSD, under supervision by Dir Petrides in the late 80’s, 15 years later proves to be quite efficient and still in good function.

The study has been carried out by SWECO International, Sweden and as sub-consultants Geoinvest Ltd.

Stockholm May 26, 2003

SWECO International

Anders Rydergren	Esbjörn Tagesson
Project Manager	Environmental Engineer

Summary

In 1987, the Government of Cyprus imposed a ban on the import of PCB-containing equipment. In the same year, a scrap metal dealer imported a large number of transformers, containing the PCB-containing oil Askarel, for the purpose of extracting the metal parts. While dismantling the transformers, the PCB-containing oil was disposed in an uncontrolled manner in a nearby closed quarry. It was estimated that about 150 m^3 of Askarel oil (PCB content 60%) was dumped.

At the time, the Government of Cyprus set up a Technical Committee to deal with the problem. After carrying out detailed investigations, mapping the polluted area and evaluation of all available data, the committee decided that the best solution was to bury the contaminated soil in two, on-site constructed cells.

Ever since the site remediation took place and the cells were constructed, public health impact and risks associated with the Askarel site have been discussed.

In 2001 SWECO International, Sweden, in co-operation with Geoinvest, Cyprus, was commissioned by The Geological Survey Department, Ministry of Agriculture, Natural Resources and Environment, Republic of Cyprus to carry out a study of the Askarel Disposal Site (Tender No. 8/2000).

The study shall identify the environmental impact from the Askarel site and provide an assessment of the risks for future spreading of contaminants and exposure to humans.

Possible remediation methods for dealing with the contaminant problem shall be described and the most feasible ones shall be compared from all relevant aspects, such as technical, environmental, social and economical. Finally, the study shall end in a recommendation and a selection of the optimum solution to the existing problem.

Initially, the study contained a data collection component where previous studies were carefully examined. The existing data were completed by comprehensive field investigations including drilling, soil, water and plant sampling, chemical analyses, air monitoring and geophysical investigations by means of georadar.

The results from the soil analyses have been compared to the Swedish Environment Protection Agency's "Guidelines for less sensitive land use (industrial areas, offices, roads, etc)". The guideline value for PCB (sum of 7 PCBs) is 7 ppm.

The investigations have shown highly PCB-contaminated soil within cell no 1, as expected, and lower contamination of PCB outside cell 2, towards northwest. The latter area, where PCB-values above 7 ppm were found, correspond well with the area where transformers were dismantled and Askarel oil was released 1987, prior to remediation. The highest PCB-values in the soil were found at a depth of 10-20 meter below today's ground level. Based on a combination of the ground levels at that time and the geological formation this PCB contamination are likely to be a result of the original dumping of Askarel oil in 1987.

No other traces of high PCB-contamination in soil occur outside the cells. The conclusion is that the cells are intact and that current contamination outside the cells origin from previous activities and not from recent spreading from the encapsulated cells. The performed georadar investigations have also shown that the bottom-linings of the cells are intact.

Sampling of groundwater from shallow monitoring wells show varying levels of PCB. Compared to "maximum concentration level" (0,5 µg/l) from "Safe drinking water act" (US EPA) half of the analyses had PCB-values below the guideline value and the highest value was around 10 times the guideline value. Those shallow monitoring wells has a low yield, almost nil, and cannot be used as ordinary wells for any practical purposes.

In addition to those moderate levels of PCB in shallow groundwater, other factors like the adhesion of PCBs to particles, the low groundwater flow and the fact that the aquifer used for drinking water and irrigation purposes is quite deep in this area and well protected from surface contamination by impermeable marls, enhance the conclusion that the risk for groundwater contamination of valuable aquifers is very low. Furthermore, the groundwater is not used for drinking water purposes in the nearby area.

The air monitoring indicates a minor release of PCB by vapour from the site. The levels of PCB in the air just above the cells are however very low and well within the limits for exposure to workers according to Swedish guidelines for occupational health.

The levels of PCB in surface soil above cell 1 have shown some values exceeding the applied guideline value, indicating that spreading by dust cannot be completely neglected. However, as the Askarel site is grass covered the amount of dust that may be released is considered low.

The levels of PCB in dust and plants in the surrounding areas are all low or below the detection limit for the analyses.

Considering the low environmental impact from the Askarel cells, no leakage from the cells could be identified, the investigations and actions taken by GSD in the late 80’s must be regarded as quite successful both concerning the design and construction of the cells as well as the delineating of the contamination. Actually only one sample of totally over 100 shows a PCB content above 50 ppm, which was the guideline value at the time.

A risk assessment presenting various exposure pathways to humans has been performed showing that most of the possible exposure ways are not relevant in this case. The only pathways that might be a risk is by inhalation of vapour or dust, but even for those pathways the risks are considered low.

A number of available remediation methods have been identified and described. Out of those available methods three were selected and further assessed in terms of social, economical, environmental and technical aspects. Those were:

Alternative 0	No action – just a limited covering of the site
Alternative 1	Incineration (permanent solution)
Alternative 2	Thermal desorption (on site treatment)

The two last alternatives will both provide a final solution by destruction of the contamination. However, the costs are high and can hardly be justified considering how limited the environmental impact is from the existing cells.

It is recommended to choose “Alternative 0, No action – just a limited covering of the site” under present circumstances. The recommendation is based on the fact that no PCB has been detected outside the cells that can reasonably be connected to any leakage from the cells. As the investigations have proved that the cells are intact, additional contribution of PCB to soil and groundwater are not likely to occur in the near future. By applying an extra soil cover the risk to inhale PCB by dust spreading will be avoided. Another simple measure is also to repair the fence around the site and thus hinder animals and unauthorised persons to enter the site.

Technically this alternative is fully viable. However, the fact that the contaminated soil and material is left to stay on the site, requires an awareness of the contaminant situation as well as it requires an awareness in future planning for the area at the responsible authorities.

The monitoring program should be followed and evaluated. However, the frequency for sampling can be reduced to once every year or every second year.

However, the recommended measure shall not necessarily be regarded as a permanent solution. By choosing alternative 0, further technical development can be followed. It is quite likely that costs for soil remediation will decrease in the future as more efficient remediation methods are identified due to the technical development.

GSD is recommended to follow the development of soil remediation methods internationally. One can well consider using the PCB cells for testing of new biological or other in-situ remediation methods, if such feasible methods should occur.

1 Introduction

In 1987, the Government of Cyprus imposed a ban on the import of PCB-containing equipment. In the same year, a scrap metal dealer imported a large number of transformers, containing the PCB-containing oil Askarel, for the purpose of extracting the metal parts. While dismantling the transformers, the PCB-containing oil was disposed in an uncontrolled manner in a nearby closed quarry. It was estimated that about 150 m^3 of Askarel oil (PCB content 60%) was dumped.

At the time, the Government of Cyprus set up a Technical Committee to deal with the problem. After carrying out detailed investigations, mapping of the polluted area and evaluation of all available data, the committee decided that the best solution was to bury the contaminated soil in two, on-site constructed cells.

Ever since the site remediation took place and the cells were constructed, public health impact and risks associated with the Askarel site has been discussed.

In 2001 SWECO International, Sweden, in co-operation with Geoinvest, Cyprus, was commissioned by The Republic of Cyprus, Ministry of Agriculture, Natural Resources and Environment, Geological Survey Department (GSD) to carry out the study of the Askarel Disposal Site (Tender No. 8/2000).

The study shall identify the environmental impact from the Askarel site and provide an assessment of the risks for future spreading of contaminants and exposure to humans. Possible remediation methods for dealing with the contaminant problem shall be described and the most feasible ones shall be compared from all relevant aspects, such as technical, environmental, social and economical. Finally, the study shall end in a recommendation and a selection of the optimum solution to the existing problem.

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2 Characteristics of PCB

2.1 Chemical Characteristics

PCB is a group of chemical substances consisting of two phenyl-rings where varying amounts of hydrogen ions are substituted with chlorine ions. Theoretically, there are 209 different PCBs, called congeners, but only some 103 are abundant in relevant amounts. PCBs are artificial molecules and therefore there are no known natural sources of PCBs.

PCBs are either oily liquids or solids that are colourless to light yellow. Some PCBs can exist as a vapour in air. PCBs have no known smell or taste. The density of PCB is usually around 1,5 kg/dm^3, i.e. heavier than water. As a group, the PCBs are considered to be semi-volatile with low solubility in water. The PCBs are persistent and have a high bio-availability.

The PCB at the Askarel site has its origin from transformer oil. The oil used is called Askarel, which is a mixture of Aroclors (commercial blends of PCBs) and trichlorobenzene. By examining the chromatograms from the soil samples analysed in the Swedish laboratory, the dominating Araclor type at the Askarel site is called Araclor 1260. This type is a light yellow, soft and sticky resin with an average of 6,3 chlorine ions per molecule. The weight percent of PCBs in Araclor 1260 is about 60 % and the density is just above 1,5 kg/dm^3.

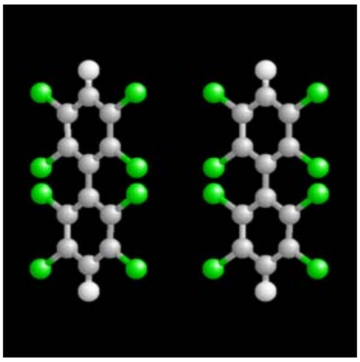


Figure 2.1. Molecule model of PCB showing different positions for chloride ions.

PCBs are persistent and do not readily break down in the environment and may thus remain there for very long periods of time. PCBs may travel long distances by air and may hence be deposited in areas far away from the release point. In water, a small amount of PCBs may remain dissolved, but mostly stick to organic particles and bottom sediments. PCBs also bind strongly to soil.

Fish and small organisms in water take up PCBs. When predators feed of these aquatic animals, PCBs accumulate in the food chain. PCBs accumulate in fish, marine mammals and birds, reaching levels that may be many thousands of times higher than in water.

2.2 Toxicity of PCB Congeners

The toxicity of the PCBs is dependent on the placement of the chlorine ions on the molecule; the most toxic congeners have a planar structure.

The most commonly observed health effects to humans exposed to large amounts of PCBs are skin conditions such as acne and rashes. Studies on exposed workers show such changes in blood and urine that may indicate liver damage. PCB exposures in the general population are not likely to result in skin and liver effects. Most studies of PCB health effects in the general population examine children of mothers who were exposed to PCBs.

Animals feeding of food containing large amounts of PCBs for short periods of time show mild liver damage and a few deaths. Animals fed with lower levels of PCBs in food over several weeks or months, developed various kinds of injuries, including anaemia; acne-like skin conditions; and liver, stomach, and thyroid gland injuries. Other impacts of PCBs in animals include changes in the immune system, behavioural alterations, and impaired reproduction.

PCBs are not known to cause birth defects.

3 Askarel Disposal Site Description

3.1 Location

The Askarel site is located on the south coast of Cyprus, west of the Ypsonas Industrial Area and outside Limassol, according to Figure 3.1.

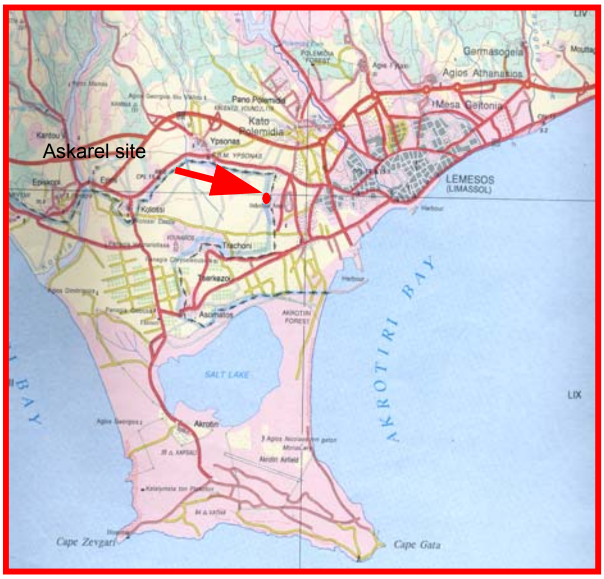


Figure 3.1. The Akrotiri peninsula with the location of the Askarel site.

The total size of the site is approximately 1 ha. The disposal site is currently flat, grass covered, with a gentle dip towards W/NW. Originally there was a small, gently sloping hill in the NS and NW/SE direction in the area (with a maximum elevation difference of ~30m). Between the 50's and the 80's, extensive excavations due to quarry activities were carried out, resulting in a dramatic change of the morphology of the site and the surroundings. These excavations were later used as uncontrolled waste disposal sites. Most of the excavations have been levelled, but some are still open. One of the excavations is a recipient of liquid wastes or treated wastewater from the industrial area.

The elevation of the broader quarry area is ranging between 44 and 12 m amsl (above mean sea level). The elevation of the investigated site is ranging between 27 and 35 m amsl.

An earth road provides access to the site through the Ypsonas Industrial Area.

Figure 3.2. View over the Askarel site towards northwest. The site is flat and covered by grass. In the background one can see industrial activities close to the site.

3.2 Present Land Use

The site, containing the two cells, is fenced to prevent access to the site. However, the fence is broken in several places and unauthorised persons may enter the site. In fact, since the site is covered with grass, a donkey has occasionally been brought to the site for grazing.

In the immediate vicinity of the site, a number of industrial activities are carried out, such as car repair shops and scrap yards with compressing and shredding of automobile bodies.

A land use map over a wider area around the Askarel site is shown in Figure 3.3.

Uncontrolled dumping of e.g. household waste, construction and demolition waste and hazardous waste is taking place nearby the site, see Figure 3.4. The dumping is somewhat taking place under commercial conditions since vehicles are used to compact and provide some cover to the dumped waste.

Figure 3.3

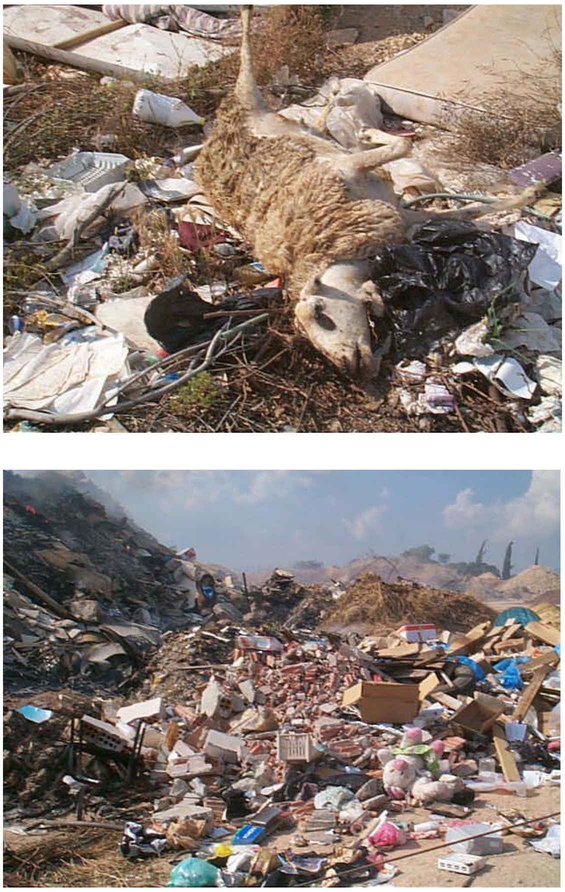


Figure 3.4. Illegal dumping of waste

During several site visits unauthorised burning of waste was observed at the illegal dumpsite, see Figure 3.5.

Figure 3.5. Unauthorised burning of waste.

Agricultural lands occupy the wider surroundings of the area. The land is among other things used as grazing for sheep and cattle, but also for fruit farming. The distance to the closest residential area is approximately 1 km.

3.3 Investigations Prior to Cell Construction

Prior to the site remediation, extensive field and laboratory works were carried out by the Geological Survey Department. These investigations are presented in a technical report completed in May, 1989 titled: “The contamination problem created to the environment due to the import of a number of transformers, their dismantling and disposal of their toxic liquid content (Askarel) to the environment”.

The investigations were carried out in 1987 and the aim was to determine the geological and hydrogeological conditions and evaluate the risk for groundwater pollution in the area. 27 boreholes (15 within the disposal site and 12 around it) were drilled and geophysical surveys, chemical analyses and collection of the available information were also carried out in order to achieve this goal.

The investigations revealed that the area consists of marls and that there is no direct hydraulic communication between the Askarel disposal site and neighbouring aquifers. Chemical analyses carried out on 17 water samples from these aquifers did not detect any contamination. However, due to the secondary permeability that is usually developed in the marl a sort of limited hydraulic communication might be developed between the contaminated site and the neighbouring aquifers. Therefore, it was concluded that in the future, the aquifers might be affected by the contaminants.

The second target of the investigations was to determine the degree and extent of contamination within the area of Askarel disposal. On the basis of 51 chemical analyses on soil samples taken from the boreholes drilled within the disposal site, it was found that the contamination extends down to more than 7 meters. Below this depth, the content of PCBs within the marl is less than 50 ppm. A total of about 11 000 m^3 of soil was found to be contaminated. Furthermore, 3 out of 28 samples taken from various plants, fruits and vegetables were contaminated most probably due to contaminated dust.

On the basis of the findings of the investigations it was proposed that:

- The contaminated soil should be buried in a specially designed, waterproof cell with a volume of 10-12,000 m^3.
- The best landfill site was the quarry, where the PCB containing oils were disposed.
- After excavation of the contaminated soil the remaining pit should be developed into a second waterproof and suitably designed cell, where various types of contaminated materials as well as contaminated soil from Limassol Port (where also dismantling of transformers was undertaken) were to be buried.
- Upon completion of the works the landfill site should be fenced and protected.

The above proposals were materialised by the personnel of GSD. and the engineers of the Water Development Department prepared the design. Some of the boreholes drilled during the drilling campaign were later used as monitoring wells. Several succeeding sampling campaigns carried out by GSD during the period 1989 – late 90´s did not detect any contamination.

3.4 Construction of Cells

The site contains two cells with PCB contaminated soil and other material, in total approximately 23 000 m^3. The cells were constructed in 1989. Cell 1 is rectangular and 50x85 m, while the shape of cell 2 is irregular and approximately 45x45 m. The bottom areas of the cells are 4460 m^2 and 1960 m^2 and the top cover area of the cells are 4250 m^2 and 1860 m^2 respectively. The bottom areas are a bit larger due to the sloping sides.

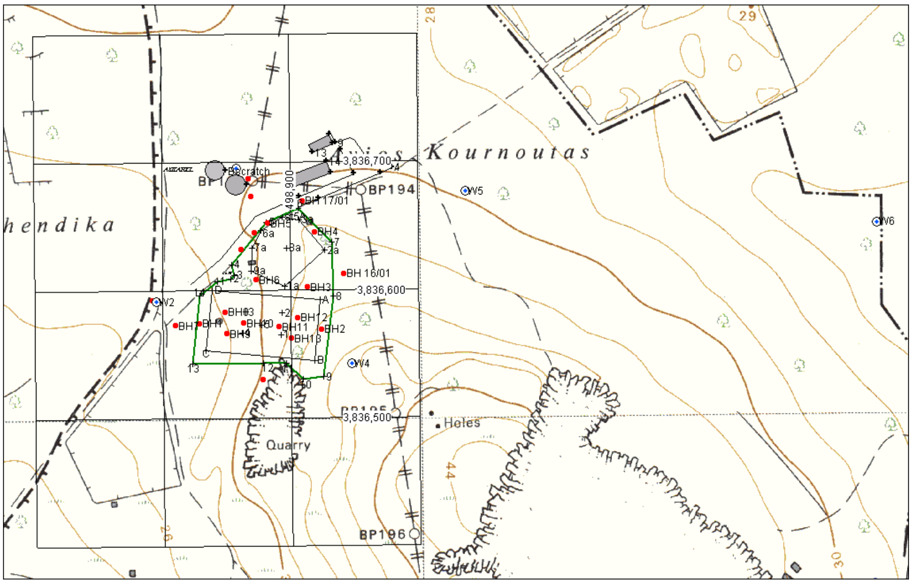
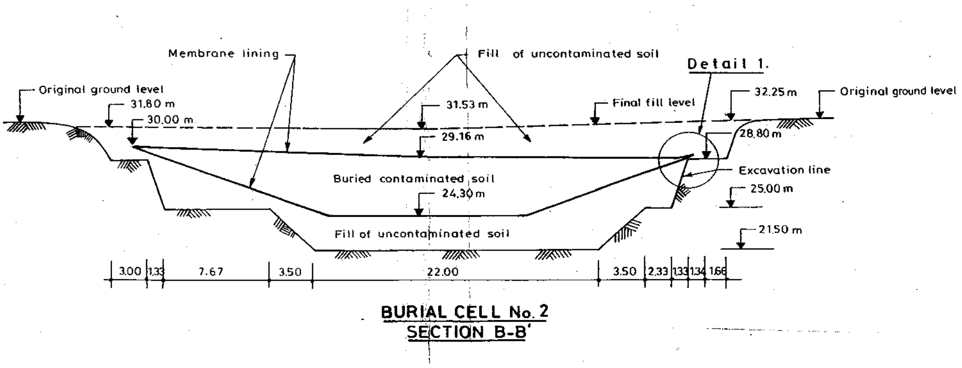


Figure 3.6. Askarel disposal site with the two cells.

As stated in the Geological Survey Department’s technical report, the contaminated part of the pit was excavated down to about 7 m, using 50 ppm as remediation limit value. All contaminated soils were concentrated and then placed in the specially designed and constructed cells, which were formed using non- or low- (<50ppm) contaminated soils as backfill material. These soils, both contaminated and non-contaminated, consist of marl or calcarenite or transitional types of the two, various imported soils of variable grain size and origin mixed with domestic and industrial wastes.

The two cells were isolated by a dual layer system, a lower layer of bentonitic clay and a second layer of high-density polyethylene membrane (HDPE) at the bottom of the cell, and the same sequence on the surface of the cell as presented in Figure 3.7. A detail of the cell lining is also shown.



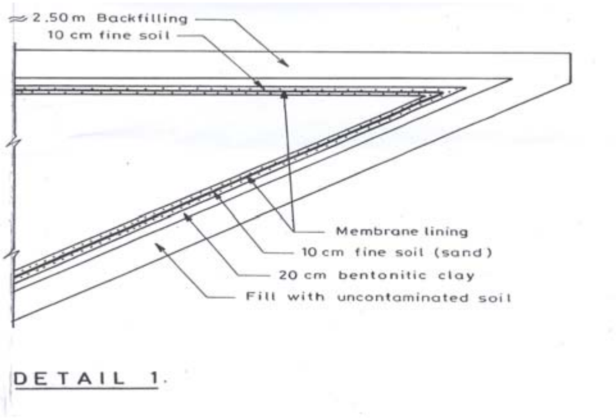


Fig. 3.7. Profiles of cell construction.

Within Cell 1, mainly contaminated soil was disposed, while in Cell 2 various materials (parts of transformers, tools, pieces of wood, drums with DDT, etc.) were also disposed.

3.5 Geological Conditions

The site geology is simple and quite uniform. The whole area is occupied by the marine, pelagic, calcareous sediments of “Nicosia Formation” of Pliocene age, capped with shallow marine deposits represented by biocalcarenites. A cross section of the cells within their geological strata is shown below.

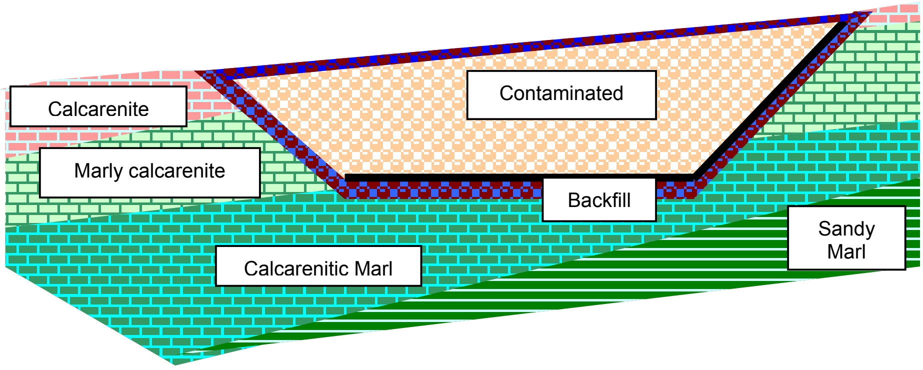


Figure 3.8. Cross-section of cell and geological strata.

Calcarenite

The thickness of the calcarenites at the Askarel disposal site is in the order of 2,5-6,5 m at the eastern and southern side. The dip of the interface of the calcarenite and the underlying marl is towards SW and SE resulting in an increase of the calcarenite thickness to more than 6 m towards these directions.

The calcarenites are poorly stratified and the stratification is imposed by slight colour and grain size changes, porosity and degree of cementation.

In general, the calcarenites are fine to mostly coarse grained, porous and variably cemented. The uppermost part has a moderate to good cementation, but it decreases gradually with depth. In certain places gravel sized black grains of igneous origin are also contained and the calcarenites turn to calcirudites.

The content of fines, i.e. silt and clay, is negligible at the uppermost part of the calcarenites but it gradually increases with depth. The calcarenites then turn to marly calcarenites and calcarenitic marls.

From the particle size and chemical composition point of view, these sediments may be characterized as calcareous sandstones. The sand content varies between 70 to 90 % and the silt content is within the range of 10 to 30 %.

The Liquid Limits are ranging between 30 and 40 % with corresponding Plasticity Indices in the order of 10 to 15 %. It is clear from the above, that the plasticity of these materials increases from low to medium on the basis of the Casagrande Plasticity Chart.

On the basis of the relation between clay content and PI (Skempton classification) these materials can be classified as normal. The Linear Shrinkage measured in combination with Atterberg Limits ranges between 0 and 8 %.

The range of moisture content is in the order of 6 %.

Transition Zone

The engineering characteristics of these materials are within the range of calcarenite and marl. These of marly calcarenites are close to those of calcarenite and these of calcarenitic marl close to the characterisation of marl.

Marl

The marl is a sandy, very clayey, siltstone of argilic-calcareous composition. It is of khaki and pale brown colour at the top, turning gradually to pale grey and grey with depth.

The differences between the marly beds are focused mainly on the colour and grain size (clay to sand and occasionally fine gravel fractions). The predominant colours are various tints of grey and khaki to pale brown. On the basis of the grain size distribution and chemical composition they are grouped into the argilaceous, calcareous mudstones. In a more detailed classification they may be classified as calcilutites, when of very fine grain size and calcisiltites, when of fine grain size. The classification of the mudstones and description on the boreholes logs was made on the basis of grain size with the aid of the sieve/hydrometer analyses. A substantial part of the mudstones encountered, however, is represented by the intermediate types (calcisiltite/calcilutite or calcisiltite/calcareous sandstones etc).

From the particle size point of view it may be characterized as sandy, very clayey, silt.

The Liquid Limit is in the order of 60-70 % with corresponding Plasticity Index in the order of 35-45 and can be classified as inorganic clay of medium to high plasticity on the Casagrande

Plasticity Chart - Soil Type CH. The intermediate types, i.e. marly calcarenite/calcarenitic marl exhibits lower Liquid Limits in the range of 45-55 %. On the basis of the relation between clay content and PI (Skempton classification) these materials can be classified as normal to active. The Linear Shrinkage measured with Atterberg Limits ranges between 16 and 19 %.

The moisture content is ranging between 20 and 35 %.

3.6 Hydrogeological Conditions

Four aquifers are present in the broad area of Akrotiri Peninsula.

- The Plio-Pleistocene deposits Aquifer and
- the Athalassa Formation Aquifer, which are underlain by the aquiclude Nicosia Marl. The latter separates the above two aquifers from
- the Pakhna Sandstone and
- the Pakhna Gypsun aquifers.

The most important and worth noticing is the Plio-Pleistocene deposits aquifer, which extends down to ~115 m below mean sea level. It is of variable thickness, a few meters at the north increasing towards south, where it attains the maximum thickness of about 120 m. The water table fluctuation is small, 5-10 m (from records of GSD).

This aquifer is underlain by the Athalassa aquifer, which is developed within the calcarenites. The latter outcrop in several places at the surface as isolated outcrops, but they are considered less interesting as aquifers due to their small thickness. No aquifer within the calcarenites, which are found topographically higher than the Plio-Pleistocene deposits, was encountered during the hydrogeological investigations carried out by Geological Survey Department. It seems that the rainwater infiltrating into the calcarenite drains to the gravel aquifer. Groundwater was found only in calcarenites underlying the Plio-Pleistocene deposits or in contact or interbedded with them and governed by their regime.

The two Pakhna aquifers are found at large depths.

At the Askarel disposal site, the thickness of the calcarenites is very small and although the thickness of the calcarenites increases towards east–west and south, its bottom level is still well above the groundwater table. Furthermore, since the calcarenite is underlain by the aquiclude marl at the Askarel site, it has no direct contact with the Plio-Pleistocene deposits aquifer.

No groundwater was struck during drilling, however, high moisture content was observed in the sandy layers (or sand rich layers) within the marl. In BH14/01, which was drilled down to 23 m, where the thickness of the calcarenite and the content of the sandy layers within the marl are higher, a static water level occurred at 22.50 m below ground level (the observation was made one day after the completion of drilling).

The permeability of the calcarenite is quite high, in the order of Ks = 1–2 m/day. The marl is of very low permeability, in theory practically impermeable. However, due to weathering, fissuring and jointing, weak secondary permeability has been developed in the uppermost part of the marl. These features in combination with the sandy layers incorporated in the uppermost part of the marl could result in the development of small, very poor and unimportant local aquifers.

The geological interpretation of the information obtained during the drilling campaigns is in agreement with the conclusions made by the Geological Survey Department in 1989; the calcarenites forming the uppermost part of the disposal site are not in direct hydraulic contact with the Plio-Pleistocene and/or the Athalassa Calcarenite aquifers. However, there is a slow flow of groundwater along the uppermost part of the sandy marl, i.e. some mm/day.

No water wells are used for drinking water purposes within the close vicinity of the site. However, groundwater from the area may be used for irrigation of crops, vegetables and fruit orchards.

3.7 Climate and Groundwater Recharge

3.7.1 Precipitation

The information given below was gathered between 1961 and 1990 and has been provided by the Meteorological Department. The precipitation measurements were taken at the Limassol Station.

Table 3.1. Precipitation data from the Limassol meteorological station.

Month	Precipitation (mm)
January	96
February	76
March	49
April	23
May	7
June	3
July	3
August	1
September	1
October	26
November	18
December	102
Annual	**435**

3.7.2 Evaporation

Cyprus is in the so-called Cs (Mediterranean) climate zone, which implies mild winters and dry hot summers with low precipitation and high evaporation. The evaporation in the area is in the order of 80% on a yearly basis.

3.7.3 Groundwater Recharge

Most of the precipitation (80%) evaporates and the remaining part is absorbed and transpired by the vegetation or as soil moist. Hence, the groundwater recharge in the area is considered to be very low. The deep lying groundwater levels are a result of this low groundwater recharge.

4 Environmental Investigations

4.1 Field Work

4.1.1 Drilling

30 exploratory boreholes with a total depth of 504 m and a maximum depth of 30 m have been drilled at and around the site. The locations of the boreholes are shown in Figure 4.2. The particulars of each borehole including method of drilling, encountered geological sequence, sampling, exact location, depth etc. are presented in the individual records of boreholes in Appendix 2. The Consultant's geologists in collaboration with the Client proposed the location of the boreholes. The surveyors of the Client determined the elevation and the coordinates of each borehole.

Drilling was performed with the auger-drilling technique since other drilling techniques need some kind of flushing media (air, water, soap, etc). The weakness of the selected technique is that it is slow and does not give 100% representative samples. However, it was considered to be the most suitable technique since no water or air is introduced and therefore there is no effect on the soil from this point of view (no dust or volatiles, oil movement etc).

Figure 4.1. Drilling at the Askarel site in June 2001.

Figure 4.2

5 of the 30 boreholes were made for the purpose of future groundwater monitoring. Those 5 holes were drilled by destructive drilling technique.

The rig used was a Schramm Rotadrill capable to handle all types of geotechnical drilling techniques (augering, coring, open hole destructive drilling), both flushing systems (i.e. air and water with or without foam), and a combination of the two.

4.1.2 Soil Sampling

Sampling from the 25 boreholes during all three drilling campaigns was performed by means of disturbed bulk samples, which were placed in airtight plastic bags. To protect the samples from drying, they were properly wrapped and stored. A total of 197 soil samples were collected for analyses.

Figure 4.3. Drilling and sampling activities.

The strategy when choosing levels for sampling from each borehole for chemical analyses was to collect samples from levels with expected contamination as well as from clean and transition levels.

Selection in the field was based on ocular inspection in combination with odour observations.

The results from the chemical soil analyses are presented in Appendix 4A.

4.1.3 Water Level Recording

A static water level was slowly developed in BH14/01, although no groundwater was struck during actual drilling (only quite high moisture content). The day after completion of drilling, a static water level was recorded at the bottom of the hole, i.e. 22.5 meters below ground level. In BH24/02 a similar water level was developed at the bottom of the hole, i.e. 24.0 meters below ground level.

4.1.4 Sealing of Boreholes

All six boreholes, drilled within Cell 1, were backfilled with the arisings upon completion of each hole. The uppermost 1 m was backfilled with bentonite slurry. A plastic tube of the same diameter as the hole was introduced into the holes and then filled with the bentonite slurry. Bentonite slurry was also applied around the plastic tubes.

The holes drilled outside the cells were also backfilled with the arisings. Thereafter, a plastic tube was placed in the hole and labelled with the number of each hole.

The five boreholes drilled for groundwater monitoring, BH26/02-BH30/02, have been equipped with standpipes in order to facilitate both water level recordings and sampling.

4.1.5 Water Sampling

Water samples have been taken from the wells drilled by GSD in 1990 for chemical analyses. Two sets of water samples were taken from six wells respectively, in summer 2001 and summer 2002. Samples were taken with pump or bailer, depending on the amount of water in the wells.

The location of the wells are shown in Appendix 1. 12 groundwater samples have been analysed in the Client laboratory. The results are presented in Appendix 4B.

4.1.6 Air Monitoring

Monitoring of PCB release by air from the surface of the cells was conducted during the periods 21st - 27th of November 2001 and 16th – 21st of May 2002. The monitoring time was about 48 hours for each sampling location.

The monitoring was made in five locations; one in the middle of cell 2, two outside the cells (but within the fenced area), one in the scrap yard north of the site and one background value was taken in Limassol. The sample locations, AM1-AM5, are shown in Appendix 1.

The three locations within the fenced area were chosen on the basis of the degree of contamination. AM1 was taken on highly, AM2 in moderately and AM3 in very low contaminated or non- contaminated area.

AM1	in the middle of cell No 2.
AM2	at the site of BH5/01
AM3	at the site close to BH20/01.

The air samples from AM1-AM3 were taken by using a cover placed on the ground thus capturing the air volume between the cover and the ground. A pump was sucking the air volume captured through a filter, removing large particles. An absorbent (XAD-2) captures the volatile and PCBs on very fine particles. The cover air intake also has a filter. Figure 4.4. presents an outline of the technical method.

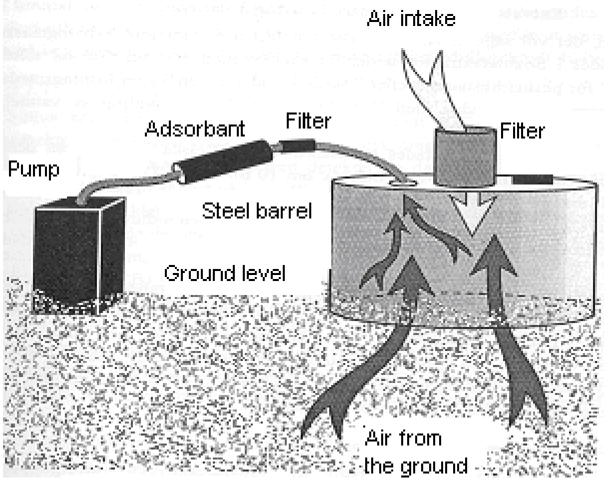


Figure 4.4. Layout for the air monitoring system.

Figure 4.5. Air monitoring at the Askarel site

The sampling in AM4 (in the scrap yard) was taken to measure the PCB-content in ambient air in the close vicinity of the site. The technique used was similar to the above described though the sampled media was ambient air instead of air released from the ground. In AM5 the same technique was used with the purpose to receive a value in a non-contaminated area (Limassol).

Totally 7 air samples have been analysed. The analyses were made in AlControl Laboratories, Sweden. The results are presented in Appendix 4C.

4.1.7 Sampling of Vegetables and Surface Soil

Sampling of vegetables and surface soil were taken in the surroundings of the Askarel site, to the north, west and southwest.

Samples of vegetables were taken from marrow leaves, orange tree leaves/green oranges, peppers, corn leaves, parsley and carob tree leaves.

Surface soil samples were taken on the upper 10 centimetres of soil in a wheat field, orange grove, pepper field, corn field, parsley field and a carob tree field.

6 surface soil samples and 6 vegetable samples have been analysed in the Client's laboratory. The results are presented in Appendix 4D.

4.1.8 Georadar Investigations

Georadar investigations were carried out in June-July 2002 in cooperation with GSD. 7 G.P.R. - Ground Penetrating Radar lines were conducted with a total length of 650 m. The results are provided in Appendix 6.

4.2 Chemical Soil Analyses

197 chemical analyses in total were performed on soil samples. About five samples per borehole were analysed. The method separates the following 6 PCB isomers: PCB 28, 52, 101, 138, 153, and 180.

For correlation and verification, control samples were analysed in the Client Laboratory at the Geological Survey Department and in Sweco's own laboratory in Sweden. The results of the duplicate sample analyses show a good correlation between the two laboratories. The results are given in Table 4.1 below.

Table 4.1. Results from the soil samples analysed in the GSD laboratory and Sweco's own laboratory (SWE). N.A means no analysis, N.D means not detected.

	BH2/01, 8-9m		**BH4/01, 1-2m**		**BH5/01, 16-17m**		**BH9/01, 2-3m**	
PCB No	**SWE**	**GSD**	**SWE**	**GSD**	**SWE**	**GSD**	**SWE**	**GSD**
PCB101	0,0008	<0,003	0,1083	0,059	6,7747	6,8	18,3689	14
PCB138	0,0039	0,003	0,4529	0,13	19,7347	24	88,4796	47
PCB153	0,0052	0,0033	0,4088	0,16	18,3284	29	101,4223	58
PCB180	0,0082	0,0042	0,4479	0,12	20,4447	28	108,2647	55
PCB28	N.D.	<0,003	N.D	0,02	1,7101	0,65	5,4555	1,9
PCB52	N.D.	<0,003	0,011	0,012	1,0805	0,56	3,243	0,92
Sum 6	**0,0181**	**<0,020**	**1,4289**	**0,5**	**68,0731**	**89**	**325,234**	**180**
PCB-118	N.A	<0,003	N.A	<0,003	N.A	<0,003	N.A	<0,003

The results of PCB 118 are all below detection limit analysed in the Client's laboratory. This indicates that PCB118 is not a relevant part

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in the composition of the Askarel oil. Hence, it is acceptable to omit PCB 118 in the interpretation of the results.

All results are presented in both tabulated form and from borehole logs (Appendices 2 and 4A).

5 Askarel Site Contamination

Under the following section, the levels of contamination within the area are described. A model including profiles, 2-dimensional and 3-dimensional maps of contamination levels is presented in Appendix 3.

It must be stressed that the Askarel site is situated within a heavily industrialised area. Hence, there is an additional environmental impact from the present activities resulting in contamination by heavy metals and different types of petroleum products. At the Askarel site however, the major and dimensioning contaminant is PCB. Therefore, the following conclusions are limited to the impact of PCB.

5.1 Soil

5.1.1 Levels of Contamination

The results from the soil analyses have been compared to the Swedish Environment Protection Agency's "Guidelines for less sensitive land use (industrial areas, offices, roads, etc)". The guideline value for PCB (sum of 7 PCBs) is 7 ppm.

Each borehole (BH) has been numbered with a serial two-digit number and a two-digit number indicating the year for drilling separated by a slash (/), e.g. BH3/01 was drilled as number 3 during year 2001.

Maximum PCB content in each borehole regardless of the depth is shown in Figure 5.1. PCB content in the upper meter of the soil profile is shown in Figure 5.2. (In the Figures only the serial numbers are shown).

Figure 5.1

Figure 5.2

When comparing the laboratory soil analyses with the guideline value, the following conclusions can be made:

- Almost all of the analysed samples show detectable levels of PCB, although very low. This could be explained due to either a low, but detectable background level or a limited contamination during drilling and management of samples.

- Six boreholes have been drilled through the upper sealing of cell 1 and samples have been taken on the contaminated soils inside the cell. As expected, most of the samples from these boreholes show high or very high levels of PCB. The analyses also indicate a fairly large heterogeneity in PCB content. Levels from less than 7 ppm up to some 480 ppm have been observed, though most of the analyses show levels in the range of 50–300 ppm. Samples from the soil above the membrane shows in two of six holes levels above 7 ppm.

- The drillings around cell 1 (BH1/01, BH2/01, BH7/01, BH14/01 and BH15/01) show very low levels of PCBs. All samples from these boreholes contain a PCB level below 1 ppm.

- Also the boreholes between the cells (BH3/01, BH6/01) and BH4/01 (situated northeast of cell 2) show low levels of PCBs, between 0-3 ppm.

- Leaking from the cells can also be evaluated by comparing PCB content in old and new boreholes. BH6/01 was drilled close to the old borehole BH120/87(7) to 12 m depth. The PCB analyses are low in all 7 samples taken at the different occasions. See Appendix 7.

- BH16/01, east of the cells, has a PCB content of 7 ppm, which is equal to the guideline value, in the upper meter. Further below, the PCB-levels are less than 1 ppm. BH17/01, north of the cells, has PCB levels less than 1 ppm.

- The highest levels of PCB outside the cells are found in BH5/01. Between 15-16 and 16-17 meters below ground surface the PCB values are 51 and 68 ppm respectively.

- The boreholes BH18/01 - BH25/02 were drilled west and northwest of BH5/01 with the purpose of delineating the contaminated area outside the cells. Those results show PCB-levels lower than the ones in BH5/01, but at some depths, levels higher than 7 ppm. BH18/01 has PCB levels just above 7ppm at 16 meters depth. BH19/01 has a maximum PCB-level of 37 ppm at the depth of 21-22 meters. BH20/01 has a maximum PCB-level of 24 ppm at 4-5 meters depth, thereafter decreasing with depth. BH21/01-BH25/01 has detectable, but low levels of PCB (<1 ppm).

To summarize, the following boreholes drilled outside the cells have PCB-levels above 7 ppm: BH5/01, BH18/01 (just above 7 ppm), BH19/01 and BH20/01.

The above results indicate that levels of PCBs in soil above 7 ppm are present only in the area west and northwest of cell 2. The fact that BH17/01 and BH21/01 have low levels shows that the spreading towards north and northwest is delineated. The extent of PCB contamination towards west has been delineated to be between BH19/01, BH20/01 and BH22/02. The limit for contamination is shown in Figure 5.1.

When analysing the depth of the PCB contaminated soil northwest of cell 2, a trend may be observed. None of the four boreholes BH5/01, BH18/01, BH19/01 and BH20/01 has levels exceeding 7 ppm in the upper part of the soil. The three boreholes BH5/01, BH18/01 and BH19/01 show higher PCB-levels within 15 and 20 meters depth, in borehole 20/01 the high PCB-levels are found between 4 and 8 meters depth.

At the time of scrapping of transformers in the 80's and the following release of Askarel oil, the ground levels at the site were lower than today due to quarry activities. The ground levels were at the time about 28 masl. (meter above sea level) in comparison to present ground levels 32 masl. The Askarel oil probably leached down through the permeable calcarenite and continued through the semi-permeable marly calcarenite/calcarenitic marl. The Askarel oil most likely followed the fractures and fissures in the calcarenite and marl dipping west-northwest resulting in spreading in this direction, where the investigations also show presence of PCB-contamination. The shallow soil samples do not show high levels of PCB, which indicates that the spreading took place in the deeper soil layers.

The area northwest of cell 2, where PCB-levels higher than 7 ppm were found, corresponds with the original area of handling of transformers and release of Askarel oil prior to the remediation. In terms of probability, the conclusion is that this area became contaminated during the handling of the transformers and prior to the remediation measures. Hence, it is reasonable to conclude that the current contamination outside the cells origin from previous activities and not from leakage from the cells. The performed georadar investigations have also proved that the bottom-linings of the cells are intact.

Furthermore, it should be observed that only BH5/01 has PCB-levels higher than 50 ppm. This implies that the excavations of contaminated soil (with the aim of removing PCB-levels >50 ppm) performed in the late 80’s were quite successful.

5.1.2 Amounts of Contaminated Soil

In the table below the volumes of the cells with contaminated soil and other materials are shown. The weight has been estimated by assuming an average density of 1.6 kg/m^3.

Table 5.1. Amount of contaminated soil and other materials in the cells.

	Volume (m^3)	**Weight (tons)**
Cell 1	14 900	23 840
Cell 2	7 900	12 640
Total	22 800	36 480

5.2 Groundwater

For PCB in groundwater there are no guideline values from the Swedish Environmental Protection Agency or the European Community. The results from the groundwater analyses have therefore been compared with guideline values for drinking water from the US Environmental Protection Agency’s “Safe drinking water act”. The maximum contamination level (MCL) is 0,5 µg/l.

When comparing the laboratory groundwater analyses with the guideline value, the following conclusions can be made:

- Generally, groundwater samples from summer 2002 shows much lower levels than samples from 2001. However, the results from the two sampling campaigns (summer 2001 and 2002) differ substantially. Well W1 has e.g. the lowest value in summer 2001 (below detection limit), while it has the highest value 2002, 1.3 µg/l.

- Four of six samples from 2001 have levels exceeding 0,5 µg/l (MCL), while only one of six samples exceeds this value 2002.

First it can be stated that the PCB-levels in groundwater samples taken within this study are fairly moderate. As most the levels are 10 times the MCL level (W2 in summer 2001), and in half of the samples the levels are below MCL. Therefore the contamination situation in the groundwater is considered moderate.

It should be noted that the risk for cross-contamination between the sampling points is considerable especially taking into consideration the low levels of pollutants, i.e. even quite small amounts of PCB is sufficient to contaminate a clean sample. All three samples taken with the same sampler have levels below detection limit. It is possible that the pump used for taking the other samples carried contaminants between the wells and samples.

5.3 Air

The air monitoring indicates that there is a minor release of volatile PCB from the site. The mean value of the two samples taken inside cell 2 indicate a release of volatile PCB of 0.6 µg/m^2,day. The mean value of the two samples taken at BH5/01 indicate a release of volatile PCB of 0.9 µg/m^2,day. One sample at BH20/01 was below the detection limit and thus shows no release of PCB.

The result from AM2 (inside cell 2) is assumed to be valid as an indication for release of PCB from both two cells. The result from AM1 (taken at BH5/01) is assumed to be valid as an indication for release of PCB from the contaminated area northwest of cell 2. The theoretical release of PCB to air is shown in the table below.

Table 5.2. Theoretical release of PCB to air.

Area	Release of PCB µg/m², day	Area m²	Total release of PCB mg/day	Total release of PCB g/year
Cell1 Cell2	0,6	4250 1860	3.7	1.4
NW of Cell 2	0,9	1 500	1.4	0.5
Total			5.1	1.9

Thus, the theoretical release is obviously very low and will be dispersed in the free air volume. The conclusion is therefore that no harmful levels of PCB get exposed to humans by inhalation of vapour at or in the vicinity of the site.

As a comparison, even the PCB concentration in the air inside the covers used for sampling is far below Swedish guideline values.

Table 5.3. Guideline values for exposure to workers (from Occupational Safety and Health Administration, Sweden).

	In the sampling cover, BH 5 (AM2)	Ambient air, scrap yard (AM4)	Acceptable exposure guidelines in Sweden
Air concentration	0.032 µg/m³	0.01 µg/m³	10 µg/m³

At Rasslebygd, a landfill in the southern part of Sweden, a project has been carried out to identify the dispersal of PCB to the environment. The landfill consists of municipal waste and by-products from the production of complete window frames containing PCB.

The PCB leakage to air from this landfill is 0.04 µg/m²,day. PCB is stronger bound to this type of product than PCB in transformer oil and thus the emission per m² is lower.

Dust

The PCB-concentration in ambient air dust in the scrap yard (AM4) was below the detection limit.

6 Risk Assessment

To evaluate the previously described contaminant situation regarding impact on humans and the environment In general, the levels and amounts of PCB has to be compared and assessed in terms of exposure pathways.

6.1 Exposure Pathways for Humans

Below a number of exposure pathways for humans are described and assessed with respect to the Askarel Site. The assessment is based on the present situation and land use.

6.1.1 Intake of Contaminated Soil

Oral exposure to PCB contaminants is assumed to occur as direct intake or through contaminated fingers and hands into the mouth. Important parameters are daily soil intake and bio-availability of the contaminants. The intake is age dependant and usually considered to be highest for small children.

This way of exposure is considered very low for the Askarel site, although the fence is broken and unauthorised persons may rather easily enter the site. The surrounding area contains several industrial activities and no children are playing in the area.

Furthermore, analyses from surface soil do not show very high levels of PCB (see the table below).

Table 6.1. PCB levels in surface soil. Levels >7 ppm in bold.

Borehole no.	BH1/01	BH2/01	BH3/01	BH5/01	BH6/01	BH7/01	BH8/01	BH9/01
PCB (ppm)	0	0,469	0,015	1,707	0,316	0,162	**20,121**	**9,569**
Borehole no.	BH10/01	BH11/01	BH12/01	BH13/01	BH15/01	BH16/01	BH17/01	BH21/01
PCB (ppm)	0,260	6,959	6,121	3,725	0,101	6,989	0	0,087

The only two samples where the PCB levels exceed 7 ppm are located within the fenced area, on top of cell 1. Hence this exposure way is almost negligible since the public do not have access inside the fenced area. This condition is of course only valid under the circumstances that the area will stay closed and undisturbed.

6.1.2 Dermal Contact with Soil and Dust

Contaminants adhering to the skin surface may penetrate the skin and get into the blood stream. The main exposed areas are hands, arms, feet, and legs. Important parameters are: the area of the skin exposed, amount of soil per skin area and the uptake of the contaminants through the skin.

The same conclusions as for the intake of soil above apply.

6.1.3 Inhalation of Vapours

Volatile contaminants in soils may be transported to the atmosphere and into buildings.

To assess this exposure pathway, air monitoring has been conducted. The results show that levels and concentrations in air released from the site are very low and well under applied guideline values. The conclusion is therefore, that no harmful levels of PCB get exposed to humans by inhalation of vapours.

We do however recommend, that development of residential areas in the vicinity of the site should be restricted, especially in combination with the other environmentally hazardous activities around the site.

6.1.4 Inhalation of Dust

Fine dust particles from the contaminated soil may be inhaled. Particles larger than 10 micrometers are to a great extent retained by the cilia in the bronchi, but may be swallowed later. Important parameters for exposure are the number of particles in inhaled air respirable fraction, breathing rate and exposure time.

A condition for this exposure way is that the dust particles are contaminated. As seen in Table 6.1 the surface soil is only contaminated in two sample points. In addition to surface samples, filtered dust has also been analysed for PCB. The result from the dust analyse gives a level below detection limits. Although since the levels of PCB in surface soil have showed some levels exceeding the applied guideline value, the spreading of dust cannot completely be neglected. The amount of dust particles that are spread, is naturally also of importance. Since the main part of the Askarel site is grass covered, the dust spreading is assumed to be low. No traces of contamination has been found in the vegetables or surface soil samples taken in the surroundings of the site, which even further enhance the conclusion that PCB spread by dust is low.

The risk from inhalation of dust is obviously low but cannot be completely neglected.

6.1.5 Intake of Drinking Water

Drinking water may be contaminated either at the source, which can be polluted ground- or surface water, or possibly by penetration into water pipes laid in areas with contaminated soil. Important parameters for exposure are the PCB concentration in the water and water consumption.

Sampling of groundwater from shallow monitoring wells show varying levels of PCB. Compared to “maximum concentration level” (0,5 µg/l) from “Safe drinking water act” (US EPA) half of the analyses had PCB-values below the guideline value and the highest value was around 10 times the guideline value. Those shallow monitoring wells has a low yield, almost nil, and cannot be used as ordinary wells for any practical purposes.

In addition to those moderate levels of PCB in shallow groundwater, other factors like the adhesion of PCBs to particles, the low groundwater flow and the fact that the aquifer used for drinking water and irrigation purposes is quite deep in this area and well protected from surface contamination by impermeable marls, enhance the conclusion that the risk for groundwater contamination of valuable aquifers is very low. Furthermore, the groundwater is not used for drinking water purposes in the nearby area.

6.1.6 Intake of Vegetables and Fruit

Plants grown on or in the area around the site may absorb contaminants through the roots or may be contaminated by deposition of dust. Important parameters for exposure are concentration in the edible part of the plant, consumption of vegetables or fruits and the fraction of consumed vegetables grown on the site.

There are basically three ways that contaminants may reach vegetables and fruits: dust spreading from the contaminated site, contaminants in the surface soil where the plants are growing and through uptake from irrigation water.

The dust analysed contained had levels of PCB below detection limit (see Appendix 4C). The water used for irrigation is taken from an aquifer not in contact with the soil layers were the presence of PCB has been analysed. The levels of PCB analysed in surface soil are very low, compared to the guideline value (see Appendix 4D). In addition to those aspects, the direct analyses of the vegetables gave the results of 0 ppm of PCB total in all six samples (Appendix 4D).

Thus, this exposure way has been thoroughly assessed and the conclusions are that no harmful levels of PCB get exposed to humans by intake of vegetables grown in the area.

Still, since several other environmentally hazardous activities are ongoing in the area we recommend that farming in the vicinity of the site should be evaluated and possibly be restricted in future land planning.

6.1.7 Intake of Fish from Nearby Surface Waters

Fish in lakes in areas around polluted sites may accumulate contaminants through particles in the water or when feeding of other marine animals. However, since there are no lakes in the vicinity of the Askarel site, the exposure way is not applicable in this case.

6.2 General Environmental Impact

A slow release of PCB combined with other polluting activities around the site may cause a slow and more long-term impact on the local ecosystem. The load from other contaminant sources than the Askarel site should be considered in order to fully assess the impact, but this is not within the scope of this project.

Apart from the direct impact on humans described above, the environmental risks in general may be important. However, many aspects commonly included in Environmental Impact Assessments are considered of less importance in this case, as the site is located within the heavily industrialised Ypsonas area. Furthermore, the area is fenced (at least partly) and does not serve as recreation area for the public or contain any rare ecological values to protect. Thus, the following factors are not further considered:

- Flora and fauna
- Recreation
- Landscape
- Cultural and religious heritage

Below some other environmental aspects are described along with the associated risks.

6.2.1 Earthquakes

The site is located in an area, where the risk for earthquakes is considered to be quite high. The peak ground acceleration (g) is assessed to be 0.360. (Reference: Lefkosia Seismic Hazard Assessment Index Map, December 2001.)

Generally, there are two factors to be taken into consideration when estimating the potential hazard for the contaminated soil cells during an earthquake: the frequency of the shock waves and the risk for large cracks in the soil occurring close to larger faults in the bedrock.

For the low frequency waves, 1-2 Hertz, the movement can be rather large. The magnitude may be in the order of some few decimetres. As the material in the cells is quite similar in density and structure as the surrounding soil they will follow the general movements of the soil mass in the vicinity. Thus, the bentonite sealing will be more or less intact after an earthquake.

For higher frequency waves, about 10 Hz, the movements will be much less, in the magnitude of some few millimetres. The size of the movements is considered to be too small to damage the bentonite sealing.

The risk for damaging a structure is also connected to the vertical slope. In this case the slope of the sealing layer is quite small.

There are two reports to Geological Survey Department from 1999 “Active Tectonic Studies in Cyprus for Seismic Risk Mitigation: The Greater Limassol Area – Final Report and Extended Outline” indicating a fault in the vicinity of the Askarel Site, called the Trakhoni Fault System.

The report states:

“Because of its nearness to Lemesos, this system is very important for the risk assessment. However, we cannot presently specify its parameters, because we do not know its length, or its geometry, exact location, Quaternary displacement nor do we know its slip-rate.”

Thus, it seems more information is necessary prior to include such vague geological interpretations into the physical planning process. We assume it is proper to await additional information concerning this fault before taking any actions.

6.2.2 Natural phenomena

The location of the site and its geomorphology are such that the site under study cannot be affected by any natural phenomena like floods, heavy storms, even tornadoes. Furthermore these phenomena are scarce and do not have any practical/essential impact on the site and more particularly on the buried cells.

6.2.3 Anthropogenic Actions

No excavations, explosions or similar activities are being practised in the area around. The activities in the closer area are focused on industry and farming.

Thus, no impact on the site or the cells is anticipated due to human activities.

7 Remediation Methods for Contaminated Soils

7.1 General Review

The objective for treatment of contaminated land is normally to secure that humans and the environment are not exposed to hazardous contaminants at harmful levels. When taking a decision regarding measures for a contaminated area the following parameters are usually taken into consideration:

- Environmental parameters
  Does the threat to humans and the environment demand a remediation?

- Economy
  Is the clean up cost justified by the benefit for the environment?

- Technical conditions
  Can existing techniques solve the contamination problem?

The remediation measures can be grouped in different categories depending on how the problem is tackled. One can e.g. apply:

1. administrative measures, such as restrictions in present or future land use, restrictions in farming or construction of wells for drinking water etc.

2. measures that aims to hinder or change the spreading of contaminants.

3. measures that are directed directly towards the contaminant source.

The last two categories are commonly further sorted into three primary strategies used separately or in conjunction to remediate most sites:

- Destruction or alteration of contaminants.

- Extraction or concentration of contaminants from environmental media.

- Immobilisation of contaminants.

Treatment technologies capable of contaminant destruction by altering their chemical structure are thermal, biological, and chemical treatment methods. The most common destruction methods are incineration, biological degradation, chemical oxidation and dehalogenation.

Treatment technologies commonly used for extraction and concentration of contaminants from environmental media include soil treatment by thermal desorption, soil washing, solvent extraction, and soil vapour extraction (SVE) and ground water treatment by either phase separation, carbon adsorption, air stripping, ion exchange, or some combination of these technologies. Selection and integration of technologies should use the most effective contaminant transport mechanisms to arrive at the most effective treatment scheme. For example, more air than water can be moved through soil. Therefore, for a volatile contaminant in soil that is relatively insoluble in water, SVE would be a more efficient separation technology than soil flushing or washing.

Immobilisation technologies include stabilisation, solidification, and containment technologies, such as placement in a secure landfill or construction of slurry walls. No immobilisation technology is permanently effective, so some type of maintenance is usually desired. Stabilisation technologies are often proposed for remediation of sites contaminated by metals or other inorganic species.

Generally, no single technology can remediate an entire site. Several treatment technologies are usually combined at a single site to get the best result.

The overall policy for the Swedish EPA concerning the priority order regarding selection of types of remediation methods (without any economical considerations) are first to choose destruction methods, thereafter concentration methods and in third hand immobilisation methods. Furthermore, it is recommended to use an established method for sites with large volumes of contaminated soil.

The different remediation methods in relation to energy consumption is summarised in the table below.

Table 7.1 Energy consumption related to different remediation methods.

Relative energy consumption	Immobilisation	Destruction	Concentration/extraction
High	Vitrification	Incineration	Thermal desorption Electro kinetic separation
Medium	Solidification Stabilisation	Dehalogenation Chemical oxidation Biological treatment, bioreactor	Soil washing (solvents) Soil washing (water) Soil washing in situ Air sparging
Low	Landfill cap	Biological treatment, composting	Separation (sieving) Free phase remediation

7.2 Local or Central Treatment

Remediation methods used directly on the site, without excavation the soil, are called *in-situ methods*. If the soil is excavated and treated locally on the site the method is called *on site* and if the soil is transported to an external site the method is called *off site*.

Using an in situ or on site treatment method normally lowers the total costs since the transportation costs are minimised. The cost for establishment of a treatment unit at the site can be substantial, but it often proves to be a cost-efficient method if the volume of the contaminated soil is large.

The choice between on site or in situ methods depends on the type of contaminant (physical and chemical parameters) as well as the type of soil, organic content, water content and so on. One negative factor for in situ techniques compared to on and off site techniques is that without excavating the soil it is difficult to measure the effectiveness and actual result of the remediation.

Another important factor in choosing remediation method is whether the techniques are tested in a full-scale or if they are still in an “innovation phase”. There may be different opinions between the actors on the market about established full-scale methods for treatment of PCB today. To our understanding the general opinion is that immobilisation and incineration are accepted as being the available full-scale methods at present.

8 Remediation Alternatives for the Askarel Site

Before discussing possible remediation methods it should be stressed that one remediation campaign was already conducted at the Askarel site in 1987. The excavation and incapsulation under the guidance of Geological Survey Department must be considered as a quite appropriate measure, especially taking into account the general level of knowledge of contaminated soils and remediation methods at that time. The applied measure is of the “immobilisation type” with additional administrative restrictions, like construction of a fence around the site and no permanent residents in the closer area.

Possible measures for remediation of the Askarel site are listed and commented below. In this assessment several parameters have been taken into consideration, such as:

- if the methods are capable of remediating the PCB-contaminated material
- if the methods are established
- site specific parameters, e.g. soil type etc.

The cost estimates are quite rough, but they will indicate the magnitude of necessary investments and in some cases also costs for monitoring. The costs are based on prices valid year 2003.

In line with the above grouping of alternative remediation methods the following alternatives are described below:

No.	Description of method	Location	Remarks
1	Leave the incapsulation as it is today.	In situ	Immobilisation and monitoring.
2	As no. 1 above, but with an additional protection layer on top of the existing site.	In situ	Immobilisation and monitoring.
3	Excavation and incapsulation at another site.	Off site	Immobilisation. Improvement of emission control and environmental impact.
4	Soil vapour extraction.	In situ	Extraction and concentration of contaminants.
5	Thermal desorption.	On site	Extraction and destruction of contaminants.
6	Incineration.	Off site	Destruction of contaminants.
7	Biodegradation.	On site	Destruction of contaminants.
8	Dehalogenation.	On/off site	Destruction of contaminants.

8.1 No Action (0-alternative)

As there are no clear indications of any spreading of contaminants from the cells the basic option is to leave the site as it is. Of course, this is the cheapest and most simple alternative. There are lots of research works on various remediation techniques going on worldwide at present and the development in this field should be followed. A decision for a complete destruction of PCBs can be taken later on, when an affordable and reliable full-scale method has been verified. However, a monitoring programme should be established with special emphasis on the impact on groundwater.

As administrative measures the fence around the site should be strengthened to keep people and animals out. Also restrictions in planning should be considered to avoid residential areas close to the site.

+: The cheapest alternative. The short-term environmental impact from excavation of the material creating increased risks for direct dermal contact as well as exposure of dust and vapour to humans is avoided.

-: In a long-term perspective a minor release of PCB to the environment cannot be completely excluded. A monitoring programme should be established and followed.

Table 8.1. Approximate annual costs associated with the 0-alternative.

Activity	Unit	Unit price €	Costs €
Sampling	8 hours	50	400
Analyses	7 samples	100	700
Evaluation	16 hours	50	800
Total			**1 900**

In addition to the annual costs there will also be a minor cost for the fence reparation.

8.2 Application of an Extra Soil Cover

This alternative is basically the same as above. However, some minor occurrence of PCB is found in the topsoil within the site. By applying an additional soil cover the risk for direct exposure to humans to this low-contaminated material as well as contaminant spreading with dust will be minimised. The cover should be applied over the entire site and be given a gentle slope towards the periphery of the site to optimise surface runoff. Thus, infiltration of rainwater to the incapsulated material below will be reduced. Establishment of natural vegetation without deep roots is an advantage to avoid erosion and increase evapotranspiration.

In addition, it is appropriate to put a “marker” between the present surface and the additional soil cover. This marker, e.g. a type of properly marked geotextile or plastic markers (same as those used for cables), shall serve as a warning that contaminated soil is present at the site. A more robust digging protection could even be used, but this will increase the cost.

+: Similar to the above alternative. The mitigating measure will decrease the environmental impact at a rather low cost.

-: In a long-term perspective a minor release of PCB to the environment cannot be completely excluded, although it will be less than in alternative 1 above. A monitoring programme is probably needed with administration and follow-up work.

The site is approximately 10 000 m^2 and it has been estimated 1 meter of soil in average per m^2 for the cover.

Table 8.2. Approximate costs for application of an extra soil cover.

Activity	Unit	Unit price €	Costs €
Material and works	10 000 m^3	10	100 000
Geotextile	10 000 m^2	2	20 000
Transportation	20 km and 10 000 m^3	0,7	140 000
Total			**260 000**

In addition to the costs for the soil cover there will be a minor cost for the fence reparation, and an annual cost for the monitoring program (approximately 1 900 €).

8.3 Incapsulation on a New Site

In order to establish a more controlled landfill, including e.g. a collection system for leachate from the landfill one alternative is to excavate the soil within the cells and find a more suitable disposal site on Cyprus.

+: The local contaminant problem at the Askarel site will be solved. The landfill shall be constructed with modern techniques and at a remote site, where the environmental impact is deemed less important. Any emissions shall be kept under strict observation.

-: A costly measure for just moving the soil to another site without any treatment. There will be a short-term environmental impact during handling the materials. Finding a site will most likely be a hot political issue, as nobody wants a landfill in his or her close surroundings.

Approximate costs for the incapsulation on a new site are shown in table 8.3 below. The costs for construction of a new landfill are based on EC standards for landfill construction for hazardous waste.

Table 8.3. Approximate costs associated with incapsulation on a new site.

Activity	Unit	Unit price €	Costs €
Excavation	23 000 m^3	5	115 000
Transportation	100 km; 23 000 m^3	0,7	1 610 000
Constructions of new landfill	12 500m^2	50	625 000
Backfill at the Askarel site	23 000 m^3	10	230 000
Total			**2 600 000**

In addition to the costs for excavation, transportation and construction of the new landfill there will be an annual cost for the monitoring program at the new site (approximately 1 900 €).

8.4 In-Situ Soil Vapour Extraction

The in-situ remediation method called soil vapour extraction (SVE), implies that an airflow is induced to the soil pores through infiltration wells open to the atmosphere by applying a vacuum to extraction wells screened in the unsaturated zone. Volatile and semi volatile contaminants tend to partite into the clean air as it moves through the soil to the extraction wells. The contaminants in the gas leaving the soil may be recovered or destroyed depending on air discharge regulations. The method can be combined with alternative 2, application of additional cover. Also reagents e.g. bacteria or heat can be added in the infiltration wells.

+: The short-term environmental impact from a remediation through excavation is avoided. The costs will be lower compared to remediation methods demanding excavation.

-: For PCB the method is still considered to be at the innovation stage and the efficiency is uncertain. The soil type (marly clay) is most likely not porous enough to allow air flowing through the whole soil matrix. The process will demand a very long time due to the low vaporisation rate for PCB and during that time there will be a need for a monitoring program. In fact, it is hard to consider it a real remediation method, as the decrease in contamination levels is deemed negligible over a long time period. This method may be better used as a measure to keep control of the emissions through vaporisation from the cells. Under any circumstances a pilot test is required. It is difficult to measure the results.

Table 8.4. Approximate costs associated with in-situ soil vapour extraction.

Activity	Unit	Unit price €	Costs €
Wells for vapour extraction	10 nos	1 000	10 000
Filter construction	Lumpsum	10 000	10 000
Total			**20 000**

In addition to the costs for wells and filter constructions there will be an annual cost for monitoring and operation and maintenance (approximately 5 000 €/year). Costs for eventual treatment of the off-gas are not included.

8.5 Thermal Desorption

Thermal desorption is implemented by heating and agitating soil while it is exposed to a carrier gas or vacuum that transport steam water and organic contaminants to a gas treatment system. The bed temperatures and retention times designed into those systems will vaporize selected contaminants, but will not oxidize or destroy them. All thermal desorption system requires treatment of the off-gas in the end of the line to remove particulates and contaminants.

+: Thermal desorption is a full-scale technology that has been proven successful for remediation of most types of soil. Thermal desorption units are transportable and can be used on the site, resulting in lower transportation costs for the soil.

-: The thermal desorption method requires a lot of energy, which makes it a fairly expensive treatment method. The soil needs to be excavated which gives additional costs together with an environmental impact during the time the remediation is conducted. The soil type (marly clay) is not ideal for thermal desorption because of the high clay content, which causes aggregates in the soil. It is necessary to apply strict regulations for working environment. In addition, there will probably be a minor short-term impact on the closer environment during the remediation period.

Table 8.5. Approximate costs associated with thermal desorption.

Activity	Unit	Unit price €	Costs €
Excavation	23 000 m^3	5	115 000€
Thermal desorption treatment	23 000 m^3	110	2 530 000€
Backfilling	23 000 m^3	5	115 000€
Establishment of treatment unit	Lumpsum	30 000	30 000€
Total			**2 800 000€**

8.6 Incineration

Incineration is performed by supplying heat from fuel combustion to cause thermal decomposition of organic contaminants through cracking and oxidation reactions at high temperatures (usually between 760 - 1,550 °C). The organic contaminants are primarily converted into carbon dioxide and water vapour. Other products of incineration can include e.g. nitrites, nitrates, and ammonia (for nitrogen-containing wastes); sulphur oxides and sulphate (for sulphur-containing wastes); and halogen acids (for halogenated wastes). Contaminated soils are commonly treated in a rotary kiln or a fluidised bed incinerator.

+: Incineration is a full-scale technology that has been proven successful for remediation of all types of soil. It is the most commonly used remediation method today for treating PCB-contaminated soil.

-: There is no such facility in Cyprus today, which means the material must be excavated and shipped to another country following all environmental regulations concerning transports of hazardous waste. Besides the transport costs also incineration itself is a quite expensive treatment. There will probably be a short-term impact on the closer environment during the remediation time.

Table 8.6. Approximate costs associated with incineration.

Activity	Unit	Unit price	Costs €
Excavation	23 000 m^3	5	115 000
Transport, land	20 km; 23 000 m^3	0.7	320 000
Transport, sea Limassol-Greece	Lumpsum		1 800 000
Backfilling	23 000 m^3	10	115 000
Incineration cost	23 000 m^3	800	18 400 000
Total			**21 000 000**

8.7 Biodegradation

Biological remediation technologies degrade organic wastes by microorganisms. Degradation alters the molecular structure of organic compounds and either simplifies the compounds into daughter products or completely breaks down the organic molecules into cellular mass, carbon dioxide, water, and inert inorganic residuals. Biological treatment of almost any organic hazardous waste can be accomplished because most organic chemicals can be degraded if the proper microbial communities are established, maintained, and controlled. For PCB biodegradation common composting is probably not sufficient. Instead the soil needs treatment in a bio-slurry reactor.

+: Compared to incineration and thermal desorption, biodegradation does most likely give lover treatment costs. The environmental impact on a wider area is probably smaller since it does not require large amounts of energy.

-: For PCB the method is innovative, and the efficiency is uncertain. The soil type (marly clay) may not be porous enough to allow good venting through the whole soil matrix. The process will take a long time compared to incineration and thermal desorption. Requires a pilot test. There will probably be a short-term impact on the close environment during the remediation time.

Table 8.7. Approximate costs associated with biological remediation.

Activity	Unit	Unit price €	Costs €
Excavation	23 000m^3	5	115 000
Biological remediation treatment	23 000m^3	110	2 530 000
Backfilling	23 000m^3	5	115 000
Establishment of treatment unit	Lumpsum	30 000	30 000
Total			**2 800 000**

8.8 Dehalogenation

Reagents are added to soils contaminated with halogenated organics. The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilisation of the contaminants. There are two types of dehalogenating processes, Base-catalysed Decomposition (BCD) and Glycolate/Alkaline Polyethylene Glycol (APEG).

For BCD the contaminated soil is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate. The mixture is heated to above 330 °C in a reactor to partially decompose and volatilise the contaminants. The volatilised contaminants are captured, condensed, and treated separately.

Glycolate is a full-scale technology in which an alkaline polyethylene glycol (APEG) reagent is used. Potassium polyethylene glycol (KPEG) is the most common APEG reagent. Contaminated soils and the reagent are mixed and heated in a treatment vessel. In the APEG process, the reaction causes the polyethylene glycol to replace halogen molecules and render the compound non-hazardous or less toxic. The reagent (APEG) dehalogenates the pollutant to form glycol ether and/or a hydroxylated compound and an alkali metal salt, which are water-soluble by-products. There is no full-scale device in Europe to de this kind of remediation, probably not in the US either.

+:

-: High clay and moisture content will increase treatment costs. The APEG/KPEG technology is generally not cost-effective for large waste volumes. Large soil volumes require large volumes of costly reagents. Incineration is usually made off site, which gives additional costs for transportation. The method requires a pilot test.

Table 8.8. Approximate costs associated with dehalogenation remediation.

Activity	Unit	Unit price €	Costs €
Excavation	23 000 m^3	5	115 000
Dehalogenation treatment	23 000 m^3	640	14 720 000
Backfilling	23 000 m^3	5	115 000
Establishment of treatment unit	Lumpsum	30 000	30 000
Total			**15 000 000**

9 Feasible Alternatives for Remediation

It is obvious that some of the described remediation alternatives are unsuitable for the Askarel site. In situ soil vapour extraction, biodegradation and dehalogenation are still on the pilot scale concerning technical liability for remediation of PCB-contaminated soil. Construction of a new landfill is very costly for just moving the soil. In addition, there will most certainly be problems in finding a new location for the landfill. Therefore the following 3 alternatives are the only ones, under present circumstances, that are conceivable:

Alternative 0	No action – just a limited covering of the site
Alternative 1	Incineration (permanent solution)
Alternative 2	Thermal desorption (on site treatment)

In the following sections the social, economical, environmental and technical aspects of the three feasible measures are analysed.

9.1 Social aspects

9.1.1 Alternative 0 - No Action – Just a Limited Covering of the Site

The public awareness of the contaminant situation will be unchanged since no actual action directed towards decontamination is made. This may cause a negative psychological effect among the people working or living in the area. The situation will also bring about uncertainties for the future. As a result of this uncertainty, the will of investing of companies for establishing of new industrial activities in the area could be negatively affected.

The additional covering of the site with clean soil will improve this situation, in means of that extra efforts for protection are made.

9.1.2 Alternative 1 - Incineration

This alternative gives, just as the alternative 2, a final solution to the problem. The fact that the contaminants are exported could give a more easily handled public opinion.

9.1.3 Alternative 2 - Thermal Desorption

This alternative provides a final solution to the Askarel problem. However, the public should be made aware of the activities at the site by e.g. an information campaign for the neighbouring people.

9.2 Economic aspects

9.2.1 Alternative 0 - No Action – Just a Limited Covering of the Site

This is the cheapest alternative. The cost for the extra soil cover is estimated at 260 000 €, besides the annual cost for monitoring.

9.2.2 Alternative 1 - Incineration

The cost for this alternative has been estimated at 21 000 000 €.

A secondary effect, as a result of the remediation, could be that the economic growth in the area, such as willingness for companies to make investments in establishing new facilities is positively affected.

9.2.3 Alternative 2 - Thermal Desorption

The cost for this alternative has been estimated to 2 800 000 €.

The same secondary effect as for Alternative 1 above can be foreseen.

9.3 Environmental Impact

9.3.1 Alternative 0 - No Action – Just a Limited Covering of the Site

The short-term environmental impact from excavation of the material creating increased risks for direct dermal contact as well as exposure of dust and vapour to humans, is avoided. Applying an extra soil cover will minimize the spreading of contaminants by dust.

In a long-term perspective a minor release of PCB to the environment cannot be completely excluded. There will be release by vapour that will be transported by air to the surroundings, though the release will not be in harmful levels to humans or the environment.

Since investigations have proved that the cells are intact, i.e. not leaking, additional contribution of PCB to soil and groundwater are not likely to occur in the near future. Though an important parameter is that artificial materials, as the plastic lining of the cells, has a limited durability. Thus, the condition of the lining can change by time, although filling of fine soil and bentonite clay supports the plastic lining.

9.3.2 Alternative 1 - Incineration

This alternative assumes that the contaminated soil is excavated and transported to Limassol port by trucks and then to nearest incineration facility by boat. Hence there will be emissions both from road- and boat transport. Transport of the soil must be made in closed containers.

During the remediation campaign there will be emissions and noise corresponding to those from a normal construction site of similar size. There will of course be an exposure risk to the workers at the site, and therefore careful instructions must be provided and followed at the site. Exposure to the public is expected to be low since there are no residential areas in the vicinity of the site. The remediation campaign can be assumed to last for some two months.

The aspects of long-term environmental impact from the contaminated soil will be almost completely eliminated. Of course minor residue amounts of PCBs will remain in soil and groundwater, although those are assumed to tolerable.

9.3.3 Alternative 2 - Thermal Desorption

This alternative assumes that the thermal desorption remediation is conducted with the unit on site. Hence, there will be emissions from transport of the unit to Cyprus and to the site. However, emissions from transport of soil to an external treatment site are avoided.

During the remediation campaign there will be emissions and noise corresponding to those from a normal construction site of similar size. Since off-gas treatment is very strict the release of contaminants through off-gas is assumed to be low. There will of course be an exposure risk to the workers at the site and therefore careful instructions must be provided and followed at the site. Exposure to the public is expected to be low since there are no residential areas in the vicinity of the site. The remediation campaign can be assumed to last for some six months.

The aspects of long-term environmental impact from the contaminated soil are almost completely eliminated. Of course minor residue amounts of PCBs will remain in soil and groundwater, although those are assumed to tolerable.

9.4 Technical Considerations

9.4.1 Alternative 0 - No action – Just a Limited Covering of the Site

Technically this alternative is fully viable. The fact that the contaminated soil and material is left on the site requires an awareness of the contaminant situation as well as it requires an awareness in future planning of the area at responsible authorities. The monitoring program has to be followed and evaluated.

9.4.2 Alternative 1 - Incineration

Incineration is a full-scale technology that has been proven successful for remediation for all types of soils. The soil must be transported in closed containers.

9.4.3 Alternative 2 - Thermal Desorption

Thermal desorption is a full-scale technology proved to be successful for remediation of most types of soils. A pilot test is required for dimensioning of the equipment.

10 Conclusions and Recommendations

According to the risk assessment, there are no urgent risks associated with the contaminant situation at the Askarel site, under present conditions.

The results from the soil analyses have been compared to the Swedish Environment Protection Agency's "Guidelines for less sensitive land use (industrial areas, offices, roads, etc)". The guideline value for PCB (sum of 7 PCBs) is 7 ppm.

The investigations have shown highly PCB-contaminated soil within cell no 1, as expected, and lower contamination of PCB outside cell 2, towards northwest. However, this contamination is likely a result of the original dumping of Askarel oil in 1987.

No other traces of high PCB-contamination in soil occur outside the cells. The conclusion is that the cells are intact and that current contamination outside the cells origin from previous activities and not from recent spreading from the encapsulated cells. The performed georadar investigations have also shown that the bottom-linings of the cells are intact.

Sampling of groundwater from shallow monitoring wells show varying levels of PCB. Compared to "maximum concentration level" (0,5 µg/l) from "Safe drinking water act" (US EPA) half of the analyses had PCB-values below the guideline value and the highest value was around 10 times the guideline value. Those shallow monitoring wells has a low yield, almost nil, and cannot be used as ordinary wells for any practical purposes.

In addition to those moderate levels of PCB in shallow groundwater, other factors like the adhesion of PCBs to particles, the low groundwater flow and the fact that the aquifer used for drinking water and irrigation purposes is quite deep in this area and well protected from surface contamination by impermeable marls, enhance the conclusion that the risk for groundwater contamination of valuable aquifers is very low. Furthermore, the groundwater is not used for drinking water purposes in the nearby area.

The air monitoring indicates a minor release of PCB by vapour from the site. The levels of PCB in the air just above the cells are however very low and well within the limits for exposure to workers according to Swedish guidelines for occupational health.

The levels of PCB in surface soil above cell 1 have shown some values exceeding the applied guideline value, indicating that spreading by dust cannot be completely neglected. However, as the Askarel site is grass covered the amount of dust that may be released is considered low.

The levels of PCB in dust, plants and surface soil in the surrounding areas are all low or below the detection limit for the analyses.

Considering the low environmental impact from the Askarel cells, no leakage from the cells could be identified, the investigations and actions taken by GSD in the late 80's must be regarded as quite successful both concerning the design and construction of the cells as well as the delineating of the contamination. Actually only one sample of totally over 100 shows a PCB content above 50 ppm, which was the guideline value at the time.

A risk assessment presenting various exposure pathways to humans has been performed showing that most of the possible exposure ways are not relevant in this case. The only pathways that might be a risk is by inhalation of vapour or dust, but even for those pathways the risks are considered low.

A number of available remediation methods have been identified and described. Out of those available methods three were selected and further assessed in terms of social, economical, environmental and technical aspects. Those were:

Alternative 0	No action – just a limited covering of the site
Alternative 1	Incineration (permanent solution)
Alternative 2	Thermal desorption (on site treatment)

The two last alternatives will both provide a final solution by destruction of the contamination. However, the costs are high and can hardly be justified considering how limited the environmental impact is from the existing cells.

It is recommended to choose “Alternative 0, No action – just a limited covering of the site” under present circumstances. The recommendation is based on the fact that no PCB has been detected outside the cells that can reasonably be connected to any leakage from the cells. As the investigations have proved that the cells are intact, additional contribution of PCB to soil and groundwater are not likely to occur in the near future. By applying an extra soil cover the risk to inhale PCB by dust spreading will be avoided. Another simple measure is also to repair the fence around the site and thus hinder animals and unauthorised persons to enter the site.

Technically this alternative is fully viable. However, the fact that the contaminated soil and material is left to stay on the site, requires an awareness of the contaminant situation as well as it requires an awareness in future planning for the area at the responsible authorities.

The monitoring program should be followed and evaluated. However, the frequency for sampling can be reduced to once every year or every second year.

However, the recommended measure shall not necessarily be regarded as a permanent solution. By choosing alternative 0, further technical development can be followed. It is quite likely that costs for soil remediation will decrease in the future as more efficient remediation methods are identified due to the technical development.

GSD is recommended to follow the development of soil remediation methods internationally. One can well consider using the PCB cells for testing of new biological or other in-situ remediation methods, if such feasible methods should occur.