ANNEX 5

Technical details on revegetation/reforestation methods in the "*Amiantos*" asbestos mine at Troodos, Cyprus

The need for rehabilitation

In addition to common reasons justifying mine restoration, in the case of the *Amiantos* asbestos mine, there were further reasons that made this need more urgent:

- The surface of the mine is occupied by asbestos wastes and rock fronts, which are potential sources of air born asbestos fibers, and therefore they should be covered by some means, to reduce fibers released in the air.
- The mine is part of the Troodos National Forest Park with the highest recreational and tourist value on the island. It is also part of a Natura 2000 area (both SPA and SCI) and has been determined as an Important Plant Area.
- It is situated very close to the main access road towards *Troodos Square*, which is the most popular mountain resort on the island.
- It is part of a very important watershed, which flows to the biggest water dam in Cyprus, whose water is used mostly for domestic purposes.

A general view of the mine prior restoration works

2. Ecological features of the area

2.1 Abiotic factors

2.1.1 General

The mine lies 34° 56´ north and 32° 55´ east, at altitudes between 1200 m and 1600 m, with a general eastern aspect. The topography is characterized by inclined areas (occupying more than 75% of the area), scattered flat areas (15%), and gullies.

2.1.2 Climate
The climate of the area is sub-humid Mediterranean with long, dry and hot summers and comparatively cold and moist winters. The mean annual precipitation is about 1000 mm, but substantial monthly precipitation (over 50 mm) occurs only from October (or November) to May. During the rest of the year, rainfall is occasional and usually below than 20 mm. Snow occurs every year and frost is common during winter months. Extreme maximum temperatures reach 33 °C to 35 °C in July and August and extreme minimum fall down to –5 °C to –7 °C nearly every January and February. The months from June to September (sometimes and October) are biologically dry months, which means that average precipitation in mm is less than the mean monthly temperature expressed in °C.

2.1.3 Geology-Soils
Geologically the area belongs to the widely known ophiolithic complex of Troodos and rocks mainly consist of serpentinized harzburgite with narrow veins of chrysotile asbestos (ultrabasic rocks).

The topsoil and subsoil over the entire mine area have been removed and the mother rock is exposed either in the form of smashed rock or rock fronts. It is worth mentioning that waste tips with a flat configuration exhibit high compaction which is the result of heavy machinery use, during mine operation. The soil around the mine is shallow (20 to 40 cm deep) except from foothill sites where deep alluvial soils are present. The soil texture is coarse, with a high proportion of fragmented rock, poor in nutrients and a high pH ranging from 8 to 9.

2.2 Biotic
2.2.1 Forest vegetation
The vegetation in the mine had been completely cleared away during mining works. However, all the mine area is surrounded by natural forest.

The predominant forest tree species is Calabrian pine (*Pinus brutia*) throughout the entire elevation zone, accompanied by small groups or scattered individuals of black pine trees (*Pinus nigra* subsp. *pallasiana*) at altitudes above 1400 m. Calabrian pine stands foster a variety of shrubs, sub-shrubs and herbs the commonest of which are: the endemic golden oak (*Quercus alnifolia*), strawberry tree (*Arbutus andrachne*), sumach (*Rhus coriaria*), wild dog rose (*Rosa canina*), rockroses (*Cistus* spp.), the endemic *Pterocephalus multiflorus*, *Helichrysum italicum*, alysson (*Alyssum cyprium* and *A. troodi*), the adventive *Eschscholzia californica* etc. Along streams, the dominant species are oriental plane (*Platanus orientalis*) and oriental alder (*Alnus orientalis*) with other hydrophilus species such as the laurel (*Laurus nobilis)*, *Arundo donax*, bramble (*Rubus sanctus*), *Mentha* spp. etc.

Several exotic species have been planted along the roads or near buildings, like the locust tree (*Robinia pseudoacacia*), the invasive *Ailanthus altissima*, and *Spartium junceum*. The endemic cedar of Cyprus (*Cedrus brevifolia*) is also of interest, though not indigenous to the area, it has been successfully used on Troodos by foresters in the past.

2.2.2 Fauna
The only animal species that could be a significant problem to reforestation works is the european hare (*Lepus europaeus*) which is known to feed on seedling shoots and debark stems of various

species. There are no other big herbivorous animals in the area. From the insects, the processionary caterpillar (*Thamaeutopoea wilkinsoni*) is known to seriously affect the foliage of *Pinus brutia* especially in artificial stands.

The area of the mine hosts large colonies of various bat species and a number of endemic birds, small mammals, insects, reptiles and amphibians which are of high conservational value. The value of the mine area is dramatically enhanced with the progress of restoration works.

3. The decision for Rehabilitation

The Ministerial Council made the following significant decisions in 1992, relating to the future of the Amiantos mine:

(a) The mining license would not be renewed.

(b) The area should be rehabilitated and the cost would be undertaken by the state - there was no provision in the mining license for the rehabilitation of the area.

(c) The *ad hoc* Ministerial Committee aided by a multidisciplinary, interdepartmental technical committee that would prepare a master plan for the future use of the rehabilitated mine area, of the buildings and other property elements in the mine.

No time target was set by those decisions, but it was clear it was highly desirable to complete the task the soonest possible. It was also a political commitment to neighboring communities, to give first priority to the stabilization of waste tips. These, under certain circumstances could endanger lives and properties downstream, especially at the village of *Amiantos* situated only one kilometer from the lower edge of the mine. The rehabilitation project started in 1995 and is not expected to conclude before 2030.

4. Earthworks

The earthworks are the responsibility of the Water Development and Geological Survey Departments (geologists, hydrologists and engineers) which of course act in the framework of the technical committee's decisions and co-operate closely with the Forestry Department which is the land owner but also the recipient of the sites to be reforested.

The objectives of the re-profiling of slopes in the mine are the following:

(a) To stabilize waste tips.

(b) To provide areas with suitable space and inclination for reforestation/re-vegetation.

(c) To reshape the waste tips so that the resulting topography blends visually as far as possible with neighboring landscapes.

One of the critical questions that had to be answered in planning the reshaping of slopes was the appropriate angle of the slope (inclination). That proved to be a compromise between the needs of reforestation works, the volume of wastes that had to be removed and thus the cost, and finally the limitations set by sites at the borders, e.g. existing natural forest uphill that could not be destroyed and the presence of streams on the foothills.

After discussions, the maximum acceptable angle of the slope in steep slopes was specified at 27º, which corresponds to an inclination of 51 percent (2 horizontal: 1 vertical). The minimum width of terraces agreed was 8 m to allow movement of trucks that would transport soil and other material.

The possibility of liquefaction has also been considered by the team, which has planned the reshaping, and it was concluded that this possibility was very low. They also carried out slope stability analyses that showed stable slopes and they designed a monitoring program for possible waste movements in the future.

A picture showing terraces after reshaping and restoration

5. Reforestation / Revegetation

5.1 Objective

The general objective is to establish at the lowest possible cost, a stable, self-maintained forest ecosystem with features similar of the neighboring forest, especially with regards to species composition and canopy cover (multistory and multispecies).

This primary objective is expected to help achieve other important objectives, which are:

- To cover exposed serpentine surfaces that are potential sources of asbestos fibers released in the air.
- To conserve the water catchment.
- To restore as much as possible the initial potential uses of the area and its aesthetic and other environmental values.

5.2 Problems

The main problems that had to be anticipated were:

(a) Complete lack of soil.

(b) High inclination over most of the area to be treated; this made it impossible to place topsoil of adequate depth and render the sites very susceptible to erosion especially during rainstorms.

(c) Undesirable properties of wastes, primarily the high Mg:Ca ratio and toxic concentrations of heavy metals characterizing ultramafic substrata.

(d) High pH value of wastes.

(e) Lack of experience in restoring similar sites and the lack of research support.

(f) High restoration cost.

5.3 The strategy adopted in reforestation

In order to achieve the primary objective it was decided to use as many different plant species as possible, mainly indigenous to the area, including trees, shrubs, sub-shrubs and perennial herbs. It was also decided to collect all the propagation material (seeds, cuttings etc) from areas adjacent to the mine, with similar altitude and rock substratum which can be of critical importance to the survival and growth of plants.

The supply and transport of suitable topsoil to cover the entire mine area was also considered necessary, and is intended to serve a dual purpose. First it would provide an appropriate growing medium for plants and mitigate the effect of the adverse chemical properties of the wastes. Secondly, it would cover potential asbestos fiber sources.

Finally it was accepted that little could be done about the problem of high inclination of re-profiled slopes. It was decided to cover the sown, inclined areas with branches (thatching) since other available alternatives- like artificial mats, mulch-mats etc - were tried and found very costly. The method of hydro-seeding that seemed to be of an acceptable cost was not available when works started.

5.4 Pre-planting site preparation

5.4.1 Flat areas

These areas do not make more than 15 % of the mine area. Trenches parallel to each other, about 70 cm deep and 50 cm wide are opened with a digger and the excavated material is evenly spread on the inter-space. Trenches are kept 6 m apart, to allow movement of trucks transporting topsoil and of other machinery.

Then, topsoil is transported and spread at a depth of 25-30 cm between trenches and about one meter in trenches. The soil is found from earthworks and road improvement works in the surrounding areas and villages, in a range of 10-15 km from the mine. Prior to transport, the soil is examined by a Committee and if found suitable is accepted and paid at a fixed price approved by the government. This price is intended to cover only the transport cost and thus its cost is strongly dependent on fuel prices.

It is estimated that about 5000 m^3 of soil are required for a hectare of land. Finally to enrich the transported soil, chicken manure is sometime added, which is the cheapest in the local market and its total cost is less than twice of that of the soil. In addition, all unwanted organic material resulting from various forest works e.g. cleaning of picnic sites, like leaves, small branches, wood bark, wood dust etc, is transported and deposited on these sites and left to decompose.

5.4.2 Inclined areas

The sloping sites have an inclination of about 27º (2:1 or 51%) or sometimes lower and the length of the slope is about 35 m. First a trench is opened with a digger at the foot of the bank, 50x100 cm and filled with topsoil with a digger. The excavated material is placed just above the trench, on the bank and thus a ridge is formed. Then, topsoil is unloaded on the top of the bank, is spread evenly over the surface of the inclined site at a depth 25-30 cm using a small bulldozer. After this, two secondary terraces 10 m apart, 100-120 cm wide are constructed with a mini digger. Before opening the higher secondary terrace, the first is filled with topsoil with a bulldozer and then the second is also covered with topsoil 40-50 cm deep. Finally at the top of the bank that is on the outer edge of the main terrace, a ridge 100 cm high is created using a digger. This ridge is planted

but also is intended to hold rainwater during winter and thus protect slopes from erosion. Chicken manure is added here too.

Schematic representation of reforestation of an inclined area

5.5 Planting and Seeding

The trenches on both flat and inclined sites, the secondary terraces as well ridges (on the top and bottom of the inclined banks) are planted with trees and shrubs following a more or less uniform pattern. The species used are shown in Table 1. It should be mentioned that most tree and shrubby species found in the adjacent forests are included in plantings. In addition to indigenous species, some other species, indigenous or adventive to Cyprus, but known to thrive in the area, are used for wildlife and landscape reasons.

Table 1: Tree and shrubby s*pecies used in planting in the Amiantos asbestos mine*

1. *Arbutus andrachne*
2. *Berberis cretica*
3. *Cedrus brevifolia*
4. *Cupressus sempervirens*
5. *Ficus carica*
6. *Juniperus foetidissima*
7. *Juniperus oxycedrus*
8. *Pinus brutia*
9. *Pinus nigra*
10. *Pistacia terebinthus*
11. *Prunus cerasus*
12. *Prunus dulcis*
13. *Quercus alnifolia*
14. *Rhus coriaria*
15. *Robinia pseudoacacia*
16. *Rosa* spp.
17. *Sorbus aria*
18. *Spartium junceum*

All other surfaces are seeded using a mixture of seeds of different species of perennial or biennial herbs, sub-shrubs, shrubs and trees. The species used are shown in Table 2. The amount of seed applied per hectare is about 25-30 Kg and the seeds of certain species are subjected to treatment

before use, as necessary. Grasses are not used because they dry out early in June or late May, becoming very flammable and so increasing fire hazard.

Table 2: Trees/shrubs and perennial species used in seeding in the Amiantos asbestos mine.

1. *Alcea rosea*
2. *Alyssum cypricum*
3. *Alyssum troodi*
4. *Cistus* spp. (two species)
5. *Eschscholzia californica*
6. *Helichrysum italicum*
7. *Phytolacca pruinosa*
8. *Pinus brutia*
9. *Pinus nigra*
10. *Pistacia terebinthus*
11. *Pterocephalus multiflorus*
12. *Rhus coriaria*
13. *Salvia fruticosa*
14. *Salvia willeana*
15. *Teucrium kotshyanum*
16. *Vicia tenuifolia*

(plus 10 species contained in a mixture purchased from abroad and used in hydroseeding together with local seed – a practice that must be revised).

It is worth mentioning that a significant number of herbs both annual and perennial, but also shrubby species, are transported with the topsoil from neighboring villages and are established in the mine naturally (like *Chenopodium*, *Erodium, Geranium, Papaver, Vitis vinifera, Graminae, Malva* etc.).

Immediately after sowing, the area is covered with branches (thatching). The branches are either the product of pruning or green fellings in adjacent forest areas or the product of cutting shrubs that regenerate from the stump like *Quercus alnifolia*, *Arbutus andrachne* etc in the forest. Cutting these shrubs along forest roads is also a fire precautionary measure.

The advantages of thatching are similar to those of mulching and include protection of soil from erosion, reduction of evaportranspiration, protection of seeds from being washed downhill by rains, soil enrichment with organic matter, reduction of soil temperature etc.

The seedlings used in plantings are produced at a Forestry Department's nursery situated at Platania forest station, about 5 Km from the mine (containerized stock). All seeds both those used in the nursery and those directly sown are collected by the Department's staff, from the area around the mine, securing in this way the right provenance and adaptation to the serpentine.

The time of planting usually does not coincide with the first good rains but it starts earlier in October, as planting must be completed by the end of November, when weather conditions are still good. This sometimes makes necessary the irrigation of plants immediately after planting. Sowing is carried out between June and November.

After planting and sowing, the following protective measures are taken:
(a) The branch layers are fixed to the ground using metallic wire and pegs.

(b) Simple and low-cost plant guards made of wire mesh are fixed around the stems of species that are damaged by hare. All species except pines are damaged by hare if not protected, especially *Robinia pseudoacacia*, *Spartium junceum*, *Clematis vitalba, Prunus* spp. etc.
(c) Some terraces are ripped before winter to increase water penetration in the soil/wastes and so reducing the possibility of damages by excessive water accumulation on terraces.

5.6 Maintenance-Tending
Maintenance and tending include the following:
(a) Irrigation through irrigation systems, supplied with water either by ground-based tanks or truck-mounted tanks. Plants are irrigated from June towards September and occasionally in October. Water springs existing in the mine are used as water sources.
(b) Weeding: weeds are not a serious problem except in some cases of rich soil, but weeding is anyway carried out since all plants to be irrigated are dug to form a water basin around them, which collects rain water too.
(c) Use of fertilizers: NPK fertilizers are applied in 2- and 3-year plants
(d) Beating up: every year in March or at the end of the year, failures are replanted.
(e) Pruning: as the planting space is small it became necessary to prune some fast growing species, notably *Robinia*, which competes for light with pines and other slow-growing species.
(f) Spraying: pines are sprayed with Dimilyn or *Bacillus thurigiensis* against *Thamauetopoea wilkinsoni* in October and early November.
(g) Fire protection: the area is protected as part of the Troodos Forest (patrols, fire look-out stations and a main forest fire station nearby).

A closer view of restored slopes

6. Discussion-Management Implications
The rehabilitation program of the *Amiantos* seems to be progressing well and about 125 ha have already been reforested.

The species selection seems to be successful, though some additional local, shrubby species should be tested and seed germinability be improved (e.g. by appropriate pre-treatment of seeds of certain "difficult" species).
Planting has been successful so far as regards to both viability and growth rate of plants as compared to plantings in undisturbed areas in Cyprus. Plant guards used to protect plants from the hare which has caused great losses in the first stages, proved very effective.
So far, supply of topsoil from neighboring areas at a reasonable cost was also good. Thatching has proved to be necessary to protect seedbeds on steep areas.

Nevertheless there are some major problems that management has to deal with in the near future. The main of these are:
(a) Plant germinability and growth on steep sites is not sufficient in many cases and this contributes to continuous erosion and further decline of the site fertility. The slope of 27º proved to be too high and this can be judged from the greater success of seedbeds on slopes with an angle of less than 15º.
(b) The total volume of topsoil required for the whole mine is huge (2.000.000 m^3) and it is questionable if such a quantity can be found in the next 10-15 years at a reasonable cost.
(c) The cost of reforestation re-vegetation in the mine is too high.
(d) No evaluation of the success of techniques / species used was done so far and this seems to be justified in view of the high work cost.
(e) The use of exotic species especially of the potentially invasive species, must probably stop and local seeds/plants must be used instead.

The contribution of each component/phase to the reforestation cost is about as follows:

- transport of soil …… 50%
- thatching …… 30%
- planting …… 5.5%
- sowing-seed collection …… 5.5 %
- others …….. 9,0%

Finally, "hydro-seeding" a restoration technique successfully applied in many countries in mine restoration works, has been introduced in 2003, and though cheaper than thatching, it is not as effective, perhaps because of erroneous application. Improvement of hydroseeding application in the mine is a must and it may contribute to significantly reducing re-vegetation costs and to increasing the area restored annually.

Results of hydroseeding (the yellow colored flowers belong to *Alyssum cypricum* *a near- endemic serpentinophilous perennial species*)