FAIR CT98-9571

"Physical and Chemical Protection of Wooden Poles against Groundline Decay and Containment of Preservative Leaching in Service"

Final Report for the Project Period

01-01-99 to **31-05-01**

(Note: Work ongoing and results accrued after 31-05-01
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1. EXECUTIVE SUMMARY

The Technical Objectives of the Project were as follows:

- To identify the appropriate Bioplast formulation and Field Liner construction for the European market.
- To identify end user requirements at an early stage of design and incorporate them in the specification before accelerated testing and application development.
- To develop method/s for applying Field Liners to wood in industrial situations but capable of transfer to field situations and scaling down to domestic applications.
- To construct a model efficacy testing system based on the operation and findings of the Research Feasibility Study.
- To test Field Liners for efficacy in preventing decay, containing leachate and resisting wear and abrasion.
- To establish long term monitoring of Field Liner performance for standards purposes and to develop a "road map" for acceptance of Field Liner products within appropriate EN standards.

These objectives were partially achieved by methodologies focusing on the following:

- Proving efficacy of Bioplast and other Field Liners against decay and leaching containment.
- Proving resistance of Bioplast and other Field Liners to abrasion and other damage.
- Developing application methods for Field Liners.
- Incorporating end-user requirements and standards compliance in the design of Field Liners.

The project work undertaken has resulted in:

- The identification of an appropriate Bioplast formulation and Field Liner construction for the European market.
- Development of suitable heat shrinking apparatus for field, retail and industrial markets.
- The concept of the Field Liner product, and its benefits being successfully introduced to the European Utilities and Telecommunications industries.
- The identification of two companies capable of manufacturing the Field Liner construction for the European market.

2. INTRODUCTION

This EU funded project examined the physical and chemical protection of wooden poles against groundline decay and containment of preservative leaching in service, via studies of the Field Liner, a biotechnological device recently developed to extend the service life of preservative treated and untreated timber. Field Liners are ‘sheaths’ consisting of an outer plastic layer of LDPE (or other) and an inner layer of polypropylene or ‘bioplast’ (plastic impregnated with a dry film biocide) and application to the pole (from the butt to above the groundline) is undertaken via heat-shrinkage.

Decay in distribution poles predominates at the groundline (Chambers, 1963; Smith and Cockroft, 1967 b, c; Anon 1971; Becker 1976) where moisture and oxygen conditions combine to provide an environment highly conducive to the proliferation of decay organisms. In temperate regions, decay is caused primarily by soft-rot fungi and basidiomycete fungi. Soft-rot fungi are aerobic soil dwellers and cause external decay around the circumference of the pole at or just below the groundline. This occurs when pre-treatment preservatives, such as creosote, begin to fall to non-toxic levels due to leaching. As the outer 5-8 cm of a typical distribution pole contains 80–90% of its bending strength (Bingel, 1988), the significance of external decay in causing pole failure is evident.

The Field Liner is intended to preclude external decay by forming a barrier between the pole and the soil thereby preventing invasion by soft rot fungi. Preservative loss from the pole groundline to the surrounding soil is also likely to be severely restricted. Indeed, there is evidence that gravitational movement of creosote increases preservative levels in the groundline region of field lined poles. Therefore, by application of Field Liners to preservative treated poles prior to erection (as a pre-treatment device) it is hypothesised that pole service life will be significantly extended and that environmental contamination by leached preservative chemicals will be substantially reduced.

Decay fungi require adequate moisture and oxygen levels for decay to take place. Wood at moisture contents below 20% (dry weight basis) or waterlogged wood, is at low risk of decay due to absence of moisture and lack of oxygen respectively. However, timber between these two states such as distribution poles in ground contact (termed Hazard Class 4 timber) or timber cladding (Hazard Class 3) is highly susceptible to decay. Therefore, to ensure adequate service life of these materials the application of pre-treatment preservatives is a fundamental requirement.

All preservatives by their nature are toxic, and all leach to some extent. Leaching of preservatives from pre-treated timber results in a reduction in long-term efficacy, contamination of the adjacent soil/water environment and promotes further chemical inputs (remedial preservatives) that are more susceptible to leaching (further environmental contamination). These factors are publicised by fibreglass, steel and concrete producers to market these materials as alternatives to timber. This, together with general environmental concerns regarding the widespread industrial use of traditional preservative constituents such as heavy metals and volatile organic compounds (VOCs), is now being translated into legislation which is restricting the use of traditional preservative types in a number of countries. The timber preservation industry is responding to this challenge in several ways:

1. Developing and/or adopting new pesticide types (e.g. azoles and quaternary ammonium compounds) and/or mixtures of these which are waterborne, more target specific, frequently synergistic in effect, and more environmentally benign.

2. Re-formulating traditional preservative types using newer and more environmentally acceptable pesticide inputs (e.g. Tanalith E containing a Copper-azole and borates).

3. Examining methods whereby the long-term efficacy of traditional preservatives (e.g. creosote) can be improved and environmental impacts reduced.

To date the newer preservative types are being recommended for timbers up to hazard class 3 (uncovered exterior out of ground contact) only. They are not recommended for hazard class 4 situations (uncovered exterior in ground contact) as they are generally susceptible to leaching. Re-formulated hazard class 4 preservative systems still leach from the treated timber to the environment and disposal of the timber may be problematic at the end of service life. Lowering initial inputs of traditional preservatives to reduce preservative loss to the environment and minimise end of life disposal problems without compromising length of service life is not feasible unless supplementary protection for the timber is provided.

The potential impact of Field Liners on the preservative industry is therefore great. Many environmentally acceptable hazard class 3 preservatives may be elevated to hazard class 4 status via the additional protection and preservative containment afforded by a Field Liner. Similarly, the leaching of re-formulated traditional type preservatives to the environment may be reduced to environmentally acceptable levels. Moreover, if it can be firmly established that the application of a Field Liner results in a gravitational increase in the levels of preservative in the groundline area, initial inputs of traditional pre-treatment preservatives could be significantly reduced. As a consequence, the poor environmental profile of traditional preservatives such as creosote may be re-evaluated.

The specific objectives of the project were:

1. To determine the robustness, long-term UV resistance and long-term preservative resistance of the Field Liner plastic material for application to field poles and stakes.

2. To assess the efficacy of Field Liner application in reducing the leaching of preservative constituents from the groundline of timber pre-treated with traditional hazard class 4 wood preservatives (CCA and creosote), and more recently developed hazard class 3 preservatives (azoles).

3. To examine the influence of Field Liner application (including dry film biocide inner layer) on the decay susceptibility of untreated and preservative treated timber.

Objective 1 was undertaken via modification of industry tests designed to assess the puncture, tear, abrasion and UV resistance of plastic materials for Field Liner usage.

Objectives 2 and 3 entailed the preparation of two laboratory-based and two field studies:

- The development of representative physical field models (soil columns) designed to facilitate accelerated leaching of preservative constituents from treated small poles of Scots pine and Sitka spruce (with and without Field Liners). The models were established to allow chemical analyses of soil, leachate and timber to be undertaken and thereby determine the influence of Field Liner application on these parameters.

- The construction of soil test-beds for accelerated decay studies of treated and untreated small stakes (treatments and species as above) in a 'fungal cellar' facility (high temperature/humidity soil environment).

Two field systems were also established to enhance and support the findings of the laboratory based studies and assess the benefits of Field Liner application under severe natural regimes:

- Replication (in terms of timbers and treatments) of the soil column studies at a West of Scotland field site to monitor similar parameters

- Replication of the soil column studies at a field site in Guadaloupe (Caribbean) to monitor similar parameters. In addition, assessments of incipient fungal decay and termite damage in the timbers were to be undertaken.

3. MATERIALS AND METHODS

3.1. Field Liner Materials Performance

3.1.1. Liner Material Manufacturing and Testing Strength Properties

Provisional Field Liner material was supplied in three forms: Polypropylene (creosote resistant), Low Density Polyethylene (LDPE) and Polyvinyl chloride. Initial testing indicated that a final Field Liner product would best be served by combining Polypropylene (for an inner creosote resistant sleeve) and LDPE (for a robust outer abrasion resistant sleeve). In practice, the outer LDPE sleeve would be that part of the Field Liner subjected to impact, tear and abrasion, and consequently these tests were undertaken using outer LDPE material only. The thickness of all material supplied was 0.75 mm.

The robustness of the LDPE as material suitable for the outer covering of the Field Liner was determined using three modified industry standard tests. These tests are designed to test **impact resistance** (BS: 2782: part 3: Method 352E: 1996. ISO 7765-1: 1998: Free-falling dart method), **tear resistance** (BS 2782: part 3: Method 360B: 1991. ISO 6383-1: 1983.), and **abrasion resistance** (BS 2782: part 3: Method 370: 1996. ISO: 1995 - Methods of testing plastics by determination of the resistance to wear by abrasive wheels). Brief details of these tests follow.

Impact Resistance: The findings are based on mean results from the free-falling dart testing procedure. Impact resistance (or impact failure mass) is calculated from the mean using a standard equation. Tear Resistance: The principle of the method is that a rectangular specimen having a longitudinal slit extending over half its length, is subjected to a tensile test on the 'trouser legs' formed by the slit. The average force required to tear the specimen completely along its length is used to calculate the tear resistance of the material under test in Newtons. These tests were undertaken on samples orientated vertically and horizontally on the Field Liner LDPE. Abrasion Resistance: The principle of the method is that two abrasive wheels are applied to the test specimen with a specified load. The wear obtained after rotation is assessed by an appropriate procedure.

The following modifications to the above standard test was:

- The disc speed of rotation was 225 revolutions per minute
- The abrasive paper used was P80 (Scotch™ Coarse*Super*Grade sandpaper. Grit P80).
- The method of assessment was time taken (minutes) for the production of a hole or tear, which is visible to the naked eye, in the test material.

No testing of material for compressive strength was undertaken as the practical use of the material for Field Liners would not result in the application of such forces. For each of the physical tests LDPE material was subjected to four treatments. These were:

- No treatment (control samples)

- Heat shrinking to represent the practical application of the material as a Field Liner;
- Freezing at -30°C to represent poor winter temperature conditions in Europe;
- And heat shrinking followed by freezing (-30°C) to represent real exposure conditions of the post-shrunk material.

The LDPE material was supplied as pre-formed small Field Liner tubes (up to 1m long with a diameter of 10-15 cm) Each tube was then heat shrunk onto a wooden pole section and allowed to cool for 1hr. The Field Liner tubes were then removed from the pole sections and samples of appropriate size cut for the physical tests. For each of the three tests, 400 samples of pre-shrunk LDPE were collected. Freezing was achieved by taking a small Field Liner (as supplied and/or pre-shrunk) and submerging it in a water-filled container. The container was placed in a freezer for one week at a temperature of -30°C. After thawing, the Field Liner was removed, dried and samples cut for testing.

3.1.2. Testing Preservative Compatibility with Field Liner Material

Tests were undertaken with 2 standard concentrate formulations of CCA and 2 standard formulations of creosote. In addition a further CCA formulation of lower concentration was produced (as used in field poles) and used in the testing procedure. As the polypropylene inner layer of the Field Liner would be exposed to these preservatives in practice, only this material was used for the tests. The test consisted of constructing 30 bags from the polypropylene material and filling each bag with the prepared preservative formulations. This procedure provided 5 replicate tests for each preservative type and 5 replicates for a water control. The preservatives were as follows:

- CCA Type 1 (32.6%CU / 41.0%Cr / 26.4%As): 95% Concentrate
- CCA Type 2 (35.0%CU / 44.0%Cr / 20.0%As): 95% Concentrate
- CCA Type 2: 3% Concentrate (as used for timber in ground contact)
- Creosote Type 1
- Creosote Type 2 (as used for overhead line support poles)

Each of 5 prepared polypropylene bags was filled with 100 ml of each preservative type (and the water control) and sealed. The filled bags were placed in a sealed container and visually examined every 2 weeks over a 4-month period.

3.1.3. Testing UV Stability of Field Liner Material

Though the testing of Field Liners for UV stability was not undertaken due to delays in receipt of UV equipment the following protocol will be followed.

As the top section of the LDPE outer layer of the Field Liner would be exposed to Sunlight in practice, only this material (50 samples) was to be exposed to a UV light source (ISO 4892-3: 1994 (E). Plastics – Methods of Exposure to Laboratory Light Sources: Part 3. Fluorescent UV Lamps. UV exposure was to be undertaken after the samples were subjected to the following pre-UV treatment regimes:

- No treatment (control samples)

- Heat shrinking to represent the practical application of the material as a Field Liner;
- Freezing at -30°C to represent poor winter temperature conditions in Europe;
- And heat shrinking followed by freezing (-30°C) to represent real exposure conditions of the post-shrunk material.

After UV treatment of the LDPE material the material will be tested for impact resistance (BS: 2782: part 3: Method 352E: 1996. ISO 7765-1: 1998: Free-falling dart method), tear resistance (BS 2782: part 3: Method 360B: 1991. ISO 6383-1: 1983.), and abrasion resistance (BS 2782: part 3: Method 370: 1996. ISO: 1995 - Methods of testing plastics by determination of the resistance to wear by abrasive wheels). These tests are detailed at section 3.1.1.

3.1.4. Establishing a Pole Preservative Specification for Use with Field Liners

Literature Search: Searching of the literature provided little information relating to methods of reduced preservative retention. One possible method employed dilution of the creosote oil with solvents. This method was judged as inappropriate given the high volumes of solvents which industry would need to employ to achieve these treatments.

Industry Discussions: Discussions were undertaken with representatives of Scottish Power (Utility), Scottish and Southern Electric (Utility), EA Technology (UK Utility research provider) and FinnForest BBH (Utility pole treater). All representatives concurred with the unsuitability of solvent dilution to achieve lower creosote retentions in timber. The majority of representatives agreed with a policy of reduced preservative retentions for environmental reasons.

3.2. Field Liner Market Requirements

3.2.1. Market Acceptance Tests and Client Co-operative Project

Market introduction and acceptance of the product was begun and continued via industry discussions concerning fit and acceptability of Field Liner usage to fence post treaters/producers, vineyard pole end-users, utility pole treaters/producers and utility pole end-users (customer requirements and preferences). A literature survey of LCA data on Field Liner materials and plastics production processes was begun but not completed within the timescale of the project.

The client co-operative project was progressed through a series of meetings with Scottish Power plc and a field site was agreed. Further progress was made towards Scottish Power plc and Finnforest BBH providing 100 medium sized creosote treated utility poles for the co-operative study. However, this was not finalised within the timescale of the project.

3.3. Field Liner Application Methods

3.3.1. Industrial Scale Application and Field Scale Application

Various heating methods were screened and options for use in industrial situations. Initially a prototype apparatus was constructed utilising gas burners surrounding a stainless steel heat shield. Samples of Field Liner, even when closely applied to the heat shield, failed to display uniform shrinkage. This resulted in tearing of the Field Liner material. It was concluded that a source of infra red radiation would be required to provide a uniform 'melt' to the Field Liner, thereby ensuring even shrinkage with no damage. Consequently, the infra-red tubular heat shrinking apparatus developed for the stage 1 feasibility study was examined for further development. It was concluded that simple improvements were achievable with relative ease. However, as this apparatus relied on an electrical power supply it was felt that this would limit the apparatus in terms of portability (i.e. for dual use at treatment plant sites and timber erection field sites). Developments of this apparatus were therefore progressed focusing on retaining the basic design with a greater diameter (to accommodate a range of pole dimensions) but basing the power source on gas (for portability).

The finished gas prototype consisted of a stainless steel tube (1.25 m long x 0.45 m in diameter). Into this steel tube were cut 8 rectangular holes measuring 20 x 6 cm. These 8 areas were sealed using rectangular steel 'shoes' each supporting a 5 piece dimpled clay gas burner head (each facing into the tube centre) each fed by a steel tube. Each steel tube was fed to a primary gas tube leading to a standard propane gas cylinder. The section of the stainless steel cylinder supporting the gas burner heads was further shielded with another cover of stainless steel (diameter 55 cm) to provide insulation to the heat source and prevent loss from the centre of the cylinder. Lighting of the burner heads was via manual spark generators inserted into 4 of the 8 burner heads.

This apparatus was tested by manually inserting pole stubs (ranging from 10-35 cm in diameter and all 3 m long) after sheathing with Field Liner material. In all cases, after an initial 5 minute period of pre-heating, the apparatus was successful in shrink wrapping the Field Liner to the pole stub. For larger dimension poles it was noted that some lack of uniformity was produced giving rise to tears in the Field Liners. It was concluded that the large dimension poles were too heavy to be manually moved within the heat cylinder with any degree of care. It was clear that this problem would be greatly increased when coping with full-length poles where manual manipulation would not be possible. This significant problem was overcome by fitting steel wheels to the base of the heat cylinder. An aluminium track (3 m long) was then constructed to accommodate the wheels and an aluminium pole (2 m) was affixed to one end of the heat cylinder. A further set of pole stubs sheathed in Field Liner sleeves were then processed. On this occasion each pole stub was supported off the ground on a wooden block in a fixed position with the heating cylinder tracking back and forth over each pole stub guided by the aluminium pole. All Field Liners were successfully applied with no damage noted to any.

Note: This apparatus was used to fit all field liners for laboratory and field studies undertaken for the project (see section 3.4 and 3.5).

3.3.2. Retail Scale Application

Retail scale application of mini Field Liners to timber fence posts was undertaken using standard domestic paint-strippers, electrical infra red industrial factory heaters, and electric infra red domestic heaters (sub-task 3.3). Applications were undertaken using more than 50 timbers. These tests were successfully concluded. Domestic paint-strippers would appear to be unsuitable for application of Field Liners as they provided high shrinkage rates on very discrete areas of the plastic material. This led to a lack of uniformity of shrinkage and tearing in more than 60% of cases. The use of electrical heaters (factory and domestic) proved much more successful with more even shrinkage being achieved and tears in the plastic being noted in less than 10% of cases. Much of the tearing associated with these latter methods appeared to be due to the operator as the tear rate consistently fell as operator experience of the method increased. The use of domestic and/or factory electrical infra red heaters provides a suitable method for application of Field Liners in domestic situations.

3.4. Field Liner Efficacy Testing with Treated Timber: Laboratory Model Systems for Accelerated Assessment.

3.4.1. Field Liner Efficacy in Reducing Leaching of Preservative Components to the Environment.

A number of physical field models (102) were constructed using bespoke geotextile woven plastic bags (100 cm long x 30 cm in diameter) each containing an internal plastic tube (100 cm long x 30 cm in diameter) as a waterproof liner. Into each bag was placed a layer of river gravel (2-3 cm in diameter) to a depth of 10 cm and above this was placed approximately 70 cm of a 1:1 mixture of river gravel and sandy clay loam soil. As each soil column was constructed, a relevant treated/untreated/Fieldlined/unlined pole was positioned.

Specific pole preservative treatments were as follows (102 poles measuring 2000 x 100 mm):

Scots pine: 12 poles (treatment: untreated)
Scots pine: 12 poles (treatment: creosote pressure treatment)
Scots pine: 18 poles (treatment: CCA pressure treatment)
Sitka spruce: 12 poles (treatment: untreated)
Sitka spruce: 12 poles (treatment: creosote pressure treated)
Sitka spruce: 18 poles (treatment: Azole 1 dip treatment)
Sitka spruce: 18 poles (treatment: Azole 2 dip treatment)

Specific Field Liner applications, to the lower 75 cm of the poles (ground contact area), were as follows (102 poles):

Scots pine: 12 poles (treatment: untreated):	6OB, 6X
Scots pine: 12 poles (treatment: creosote pressure treatment):	6OI, 6X
Scots pine: 18 poles (treatment: CCA pressure treatment):	6Oo, 6OB, 6X
Sitka spruce: 12 poles (treatment: untreated):	6OB, 6X
Sitka spruce: 12 poles (treatment: creosote pressure treated):	6OI, 6X
Sitka spruce: 18 poles (treatment: Azole 1 dip treatment):	6Oo, 6OB, 6X
Sitka spruce: 18 poles (treatment: Azole 2 dip treatment):	6Oo, 6OB, 6X

Where: **O:** LDPE Field Liner outer layer; **Oo:** Outer LDPE layer only; **I:** Polypropylene inner layer; **OI:** Outer LDPE + inner polypropylene layer; **B:** Bioplast polypropylene inner layer; **OB:** Outer LDPE + Bioplast inner; **X:** No Field Liner.

Note: A further 21 poles without Field Liners (3 for each preservative treatment) were retained for analysis of original preservative contents.

After completion, each soil column with pole was tested for stability, pierced at the base and placed in a large volume horticultural plant container (measuring approximately 10 cm in depth and 40 cm in diameter) for leachate collection. Once completed, the models were arranged randomly indoors. The original simulated rainfall regime for these models was to represent rainfall rates in the West of Scotland with an acceleration factor of 4 (i.e. simulated rainfall levels calculated from a 1 year period in the field, applied over a 3 month period).

Collections of leachate samples as the 'rainfall' regime progressed, and collections of soil and pole material samples at the midpoint (6 month equivalent) and the completion of the regime (12 month equivalent) were to be made. Comparative chemical analysis of the collected samples was intended to demonstrate the efficacy of the Field Liner in significantly reducing preservative movement from the timber via rainfall to the soil environment.

3.4.2. Field Liner Efficacy in Reducing Decay of Treated Timber.

Nine test beds (950 x 450 mm) were constructed in a fungal cellar (temperature/relative humidity: 27°C and 85%). Each test bed contained sieved non-sterile sandy loam soil to a depth of 800 mm. The bottom 60 mm of the beds consisted of pea gravel (2-5 mm diameter) to allow excess water to drain freely out of 4 holes drilled approximately 10 cm above the base of the test beds. After construction of the test beds, water was added until excess was seen to drain out of all four holes in the base (providing soil at field holding capacity (FHC)). Treated stakes (153) were then inserted. Relevant treated/untreated/Fieldlined/unlined stakes were then randomly positioned in the soilbeds.

Specific stake preservative treatments were as follows (153 stakes measuring 750 x 20 x 20 mm):

Scots pine: 33 stakes (treatment: untreated)
Scots pine: 15 stakes (treatment: creosote dip treatment)
Sitka spruce: 33 stakes (treatment: untreated)
Sitka spruce: 24 stakes (treatment: CCA pressure treated)
Sitka spruce: 24 stakes (treatment: Azole 1 dip treatment)
Sitka spruce: 24 stakes (treatment: Azole 2 dip treatment)

Specific Field Liner applications, to the lower 65 cm of the stakes (ground contact area), were as follows (153 stakes):

Scots pine: 33 stakes (treatment: untreated):	9Oo, 9Bo, 9OB, 6X
Scots pine: 15 stakes (treatment: creosote dip treatment):	9OI, 6X
Sitka spruce: 33 stakes (treatment: untreated):	9Oo, 9Bo, 9OB, 6X

Sitka spruce: 24 stakes (treatment: CCA pressure treated): 9Oo, 9OB, 6X
Sitka spruce: 24 stakes (treatment: Azole 1 dip treatment): 9Oo, 9OB, 6X
Sitka spruce: 24 stakes (treatment: Azole 2 dip treatment): 9Oo, 9OB, 6X

Where: **O:** LDPE Field Liner outer layer; **Oo:** Outer LDPE layer only; **I:** Polypropylene inner layer; **OI:** Outer LDPE + inner polypropylene layer; **B:** Bioplast polypropylene inner layer; **OB:** Outer LDPE + Bioplast inner; **X:** No Field Liner.

Note: A further 18 stakes without Field Liners (3 for each treatment) were retained for analysis of original preservative contents.

Removal of 57 stakes from the test beds was undertaken 6 months after exposure to the fungal cellar conditions as follows:

Scots pine: 12 stakes (treatment: untreated): 3Oo, 3Bo, 3OB, 3X
Scots pine: 6 stakes (treatment: creosote dip treatment): 3OI, 3X
Sitka spruce: 12 stakes (treatment: untreated): 3Oo, 3Bo, 3OB, 3X
Sitka spruce: 9 stakes (treatment: CCA pressure treated): 3Oo, 3OB, 3X
Sitka spruce: 9 stakes (treatment: Azole 1 dip treatment): 3Oo, 3OB, 3X
Sitka spruce: 9 stakes (treatment: Azole 2 dip treatment): 3Oo, 3OB, 3X

The below ground area of each stake was examined for decay via weight loss and surface softness (arbitrary measure by penetration test). It was intended to remove a further set of test stakes for analysis after 12 months exposure to the test conditions.

3.5. Field Liner Efficacy Testing with Treated Timber: Field Studies for Assessment.

3.5.1. Field Liner Efficacy in Reducing Leaching of Preservative Components to the Environment (*UK field site*)

This field study was designed to enhance and support the findings of the accelerated leach model described in section 3.4.1. Pole sizes, treatments and Field Liner applications were identical to those described for the accelerated leach study (section 3.4.1). This provided 102 treated poles for placement at the field site together with a further 21 poles without Field Liners (3 for each preservative treatment) which were retained for analysis of original preservative contents. The field site was situated in a high rainfall area in the West of Scotland.

It was intended that 51 poles be uplifted for analysis of preservative constituents after 6 months and 12 months field exposure for comparison with the laboratory leach model timber results (section 3.4.1) as follows:

Scots pine: 6 poles (treatment: untreated): 3OB, 3X
Scots pine: 6 poles (treatment: creosote pressure treatment): 3OI, 3X
Scots pine: 9 poles (treatment: CCA pressure treatment): 3Oo, 3OB, 3X
Sitka spruce: 6 poles (treatment: untreated): 3OB, 3X
Sitka spruce: 6 poles (treatment: creosote pressure treated): 3OI, 3X
Sitka spruce: 9 poles (treatment: Azole 1 dip treatment): 3Oo, 3OB, 3X

Sitka spruce: 9 poles (treatment: Azole 2 dip treatment): 3Oo, 3OB, 3X

3.5.2. Field Liner Efficacy in Reducing Leaching of Preservative Components to the Environment and in Reducing the Effects of Termite Attack (*Guadaloupe field site*)

This field study was designed to support the findings of the accelerated leach model described in section 3.4.1 and establish the efficacy of Field Liners in reducing/controlling termite attack of treated timbers. Pole sizes, treatments and Field Liner applications were identical to those described for the accelerated leach study (section 3.4.1). This provided 102 treated poles for placement at the field site together with a further 21 poles without Field Liners (3 for each preservative treatment) which were retained for analysis of original preservative contents. The field site was situated at an active termite site in a cleared forest area in Guadaloupe.

It was intended that 51 poles be uplifted (at 6 and 12 months) for analysis of preservative constituents (for comparison with the laboratory leach model timber results (section 3.4.1)) and termite attack determinations as follows:

Scots pine: 6 poles (treatment: untreated): 3OB, 3X
Scots pine: 6 poles (treatment: creosote pressure treatment): 3OI, 3X
Scots pine: 9 poles (treatment: CCA pressure treatment): 3Oo, 3OB, 3X
Sitka spruce: 6 poles (treatment: untreated): 3OB, 3X
Sitka spruce: 6 poles (treatment: creosote pressure treated): 3OI, 3X
Sitka spruce: 9 poles (treatment: Azole 1 dip treatment): 3Oo, 3OB, 3X
Sitka spruce: 9 poles (treatment: Azole 2 dip treatment): 3Oo, 3OB, 3X

4. RESULTS

4.1. Field Liner Materials Performance

4.1.1. Liner Material Manufacturing and Testing Strength Properties

Impact Resistance: All figures are based on mean results from the free-falling dart testing procedure. Impact resistance (or impact failure mass) is calculated from the mean using a standard equation. The following figures indicate the mean impact resistance (g) of the LDPE Field Liner material after exposure to the various treatments shown:

No Treatment:	527g
Freezing:	563g
Heat Shrunk:	588g
Heat Shrunk + Freezing:	580g

The results show that freezing, heat shrinking + freezing, and heat shrinking increase the impact resistance of the Field Liner LDPE by 6.83, 10.06 and 11.57% respectively. This was determined as being primarily due to the thickening effect of the exposure regimes on the Field Liner material resulting in greater robustness.

Tear Resistance: The following figures indicate the mean tear resistance (g) of vertically and horizontally orientated LDPE Field Liner material after exposure to the treatments shown (standard deviations are in parenthesis):

	Vertical Samples	**Horizontal Samples**
No Treatment:	177.79 (5.53)	51.33 (6.84)
Freezing:	163.75 (4.03)	43.93 (3.58)
Heat Shrunk:	181.49 (7.29)	48.18 (6.21)
Heat Shrunk + Freezing:	138.68 (5.09)	45.15 (5.48)

A full statistical analysis was undertaken for the results of the tear resistance tests. These analyses show that, for vertically orientated samples, heat shrinking alone has no significant effect on the tear resistance ($p < 0.001$) while freezing alone slightly decreases the tear resistance ($p < 0.001$). Freezing of the heat-shrunk material appears to have a significant effect on the tear resistance ($p < 0.001$). The results for the horizontal tear resistance show that there is no significant difference in the tear resistance for any of the four treatments ($p > 0.05$). The results also show that the vertical tear resistance is 3-4 times that of the horizontal tear resistance. This is related to the molecular structure of the LDPE and to the gross structure of the plastic.

Abrasion Resistance: The following figures indicate the mean abrasion resistance (minutes) of LDPE Field Liner material after exposure to the treatments shown (standard deviations are in parenthesis):

	Time to Failure (minutes)
No Treatment:	40.60 (3.80)

Freezing: 41.45 (2.13)
Heat Shrunk: 48.65 (3.68)
Heat Shrunk + Freezing: 58.35 (4.37)

Heat shrinking followed by freezing significantly increases the abrasion resistance of the Field Liner material.

4.1.2. Testing Preservative Compatibility with Field Liner Material

No failure of any of the Field Liner container bags was noted over the 4-month period of the lab preservative compatibility test. The bags were then emptied and, after suitable cleaning procedures, samples of the internal surfaces were examined for signs of disruption under a scanning electron microscope. By comparison with samples exposed to water, no overt disruption of any kind was noted for samples exposed to any of the CCA or Creosote formulations.

4.1.3. Testing UV Stability of Field Liner Material

This sub-task was not completed within the timeframe of the project.

4.1.4. Establishing a Pole Preservative Specification for Use with Field Liners

The conclusion of all industry discussions relating to the provision of a preservative specification for use with Field Liners was that Field Liners should not encourage use of lower creosote or CCA preservative retentions in the timber than used at present. Though application of a Field Liner to the groundline of a utility pole is likely to reduce creosote depletion and fungal attack of that area thereby supporting reduced creosote retentions to achieve the same pole service life. However, other pole decay patterns such as top rot (basidiomycete decay away from the groundline), which are presently minor problems, would become major problems as a consequence of using reduced preservative retentions. Reduced retentions would be lost more quickly from the timber by weathering processes. Results of field trials and laboratory studies of Field Lined timber treated with Hazard Class 3 preservatives (Azoles) awaited to determine correct retentions for these preservatives for timber in Hazard Class 4 situations (in-ground contact and uncovered).

4.2. Field Liner Market Requirements

4.2.1. Client Co-operative Project and Market Acceptance Tests

NB: The Client Co-operative study was not completed within the timescale of the project

The outcomes of market acceptance discussions to gauge the requirements/preferences of Fence post treaters/producers, Vineyard pole end-users, Utility pole treaters/producers and Utility pole end-users (utility companies) were as follows:

Fence post treaters/producers (requirements/preferences):

- A: Better durability of finished product (preservative treated fence post): Score 9

- B: Better or equal durability of finished product (untreated poles for equestrian fences): Score 9
- C: Field Liner cost < or = 10 % cost of present treated or untreated fence post (including labour and energy): Score 10
- D: Ease of application (no specialist training): Score 8
- E: Safety of application technology (no extreme Health and Safety issues to be addressed): Score 7
- F: Robustness of material (to allow agricultural fences to be relocated without replacing Field Liner): Score 7
- G: Robustness of material (to permit pile driving of fence posts without Field Liner damage): Score 7
- H: Application to newly treated timber (i.e. before drying to reduce stacking/de-stacking/re-stacking problems): Score 5
- I: Application to timbers of varying dimensions: Score 6

Customer Requirements	**Field Liner Engineering Aspects (FLEA)**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
A / 9				■	■		■
B / 9				■	■		■
C / 10	■	■	■				
D / 8			■				
E / 7		■	■				
F / 7					■		
G / 7					■		
H / 5			■	■			
I / 6			■			■	

FLEA 1: Bulk Supply (Low cost)
FLEA 2: Heat Shrinking Technology (CE Certificated and Low Cost)
FLEA 3: Heat Shrinking Technology (Ease of use)
FLEA 4: Field Liner Material, Preservative Resistance
FLEA 5: Robustness of LDPE Outer Sleeve
FLEA 6: Field Liner Material, Adaptability in Shrinkage
FLEA 7: Field Liner Material, Resistance to UV and Microbiological Degrade

Vineyard pole end-users (requirements/preferences):

- A: Equal or better durability of finished Field Lined untreated product compared to present treated product (to negate the use of preservatives to prevent soil contamination and possible grape tainting issues): Score 10
- B: Equal or reduced cost of finished Field Lined untreated product compared to present treated product (Field Liner application to equal or better the cost of present preservative treatments): Score 8
- C: Use of Field Liner with presently little utilised hardwood species to gain much better durability of products (to reduce crop disturbance due to pole replacement): Score 7

Customer Requirements	**Field Liner Engineering Aspects (FLEA)**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
A / 10					■		■
B / 8	■	■					
C / 7					■	■	■

FLEA 1: Bulk Supply (Low cost)
FLEA 2: Heat Shrinking Technology (CE Certificated and Low Cost)
FLEA 3: Heat Shrinking Technology (Ease of use)
FLEA 4: Field Liner Material, Preservative Resistance
FLEA 5: Robustness of LDPE Outer Sleeve
FLEA 6: Field Liner Material, Adaptability in Shrinkage
FLEA 7: Field Liner Material, Resistance to UV and Microbiological Degrade

Utility pole treaters/producers (requirements/preferences):

- A: Acceptability of Field Liner to end-users (utility companies): Score 10
- B: Better durability of finished product (utility pole): Score 8
- C: Reduction in soil contamination due to use of treated timber poles (improved environmental impact assessment of finished product): Score 6
- D: Field Liner cost < or = 20 % cost of present treated or untreated fence post (including labour and provided this is acceptable to end-users): Score 6
- E: Ease of application (no specialist training): Score 8
- F: Safety of application technology (no extreme Health and Safety issues to be addressed): Score 9
- G: Robustness of material (to allow long distance transport of poles): Score 9
- H: Robustness of material (to permit pole erection without damage to sleeve): Score 7
- I: Application to newly treated timber (i.e. before drying to reduce stacking/de-stacking/re-stacking problems): Score 8
- J: Field Liner usage to integrate seemlessly into existing processing (no excessive additional time inputs): Score 9
- K: No disruption of handling and storage: Score 9

Customer Requirements	**Field Liner Engineering Aspects (FLEA)**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
A / 10	■			■	■	■	■
B / 8				■	■	■	■
C / 6				■	■		■
D / 6	■	■					
E / 8		■	■				
F / 9		■					
G / 9					■		
H / 7					■		
I / 8				■			
J / 9	■		■			■	
K / 9	■		■	■	■	■	■

FLEA 1: Bulk Supply (Low cost)
FLEA 2: Heat Shrinking Technology (CE Certificated and Low Cost)
FLEA 3: Heat Shrinking Technology (Ease of use)
FLEA 4: Field Liner Material, Preservative Resistance
FLEA 5: Robustness of LDPE Outer Sleeve
FLEA 6: Field Liner Material, Adaptability in Shrinkage
FLEA 7: Field Liner Material, Resistance to UV and Microbiological Degrade

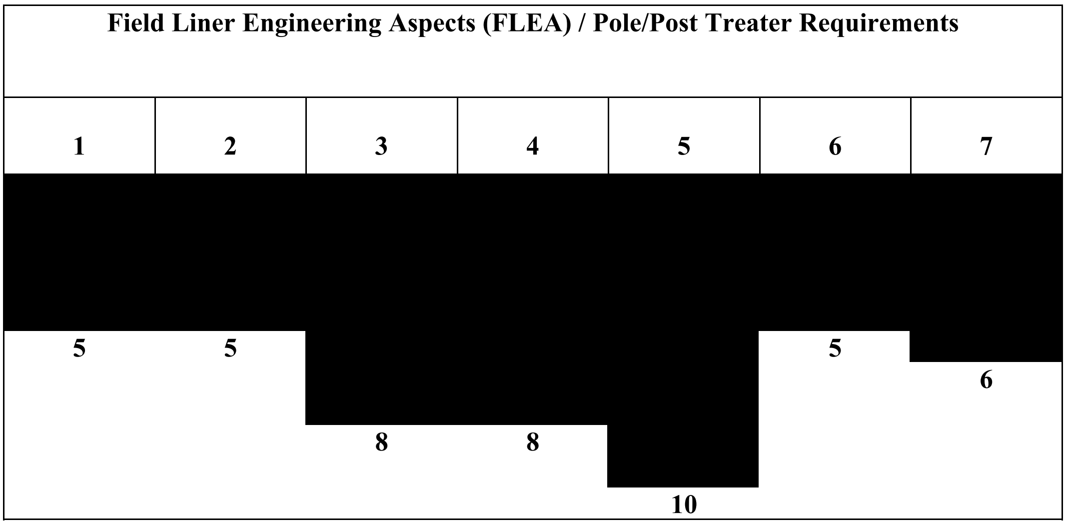
Utility pole end-users – utility companies (requirements/preferences):

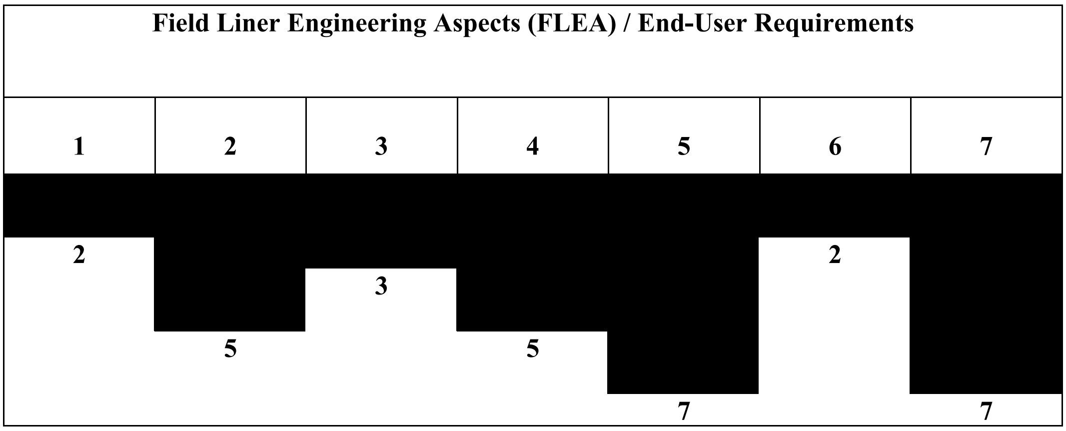
- A: Field Liners permit improved durability (greater pole service life): Score 10
- B: Use of Field Liners allow reduced cycles of condition monitoring of poles (cost savings) to enable FLs to be purchased from existing budgets: Score 10
- C: Use of Field Liners permit less recourse to supplemental preservative treatments (cost savings): Score 8
- D: Field Liners permit sub-standard treated poles to be erected without concerns regarding early deterioration: Score 9
- E: Field Liners permit the use of refractive and cheaper timbers for poles (e.g. Spruce): Score 6
- F: Ease of application (no specialist training): Score 7
- G: Safety of application technology (no extreme Health and Safety issues to be addressed): Score 10
- H: Mobility of application technology for in-situ application immediately prior to pole erection: Score 9
- I: Maximum cost of Field Liners to be approximately 15 – 20 % of treated pole cost: Score 10
- J: Robustness of material (to allow long distance transport of poles): Score 9
- K: Robustness of material (to permit pole erection without damage to sleeve): Score 8
- L: Reduction in soil contamination due to use of treated timber poles (improved environmental impact assessment of finished product): Score 5
- M: Field Liners to permit standardisation of treated pole products preventing ‘hot-spots’ of decay due to differences in topography, soil type and rainfall patterns: Score 9

Customer Requirements	**Field Liner Engineering Aspects (FLEA)**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
A / 10				■	■		■
B / 10				■	■		■
C / 8				■	■		■
D / 9				■	■		■
E / 6				■	■		■
F / 7		■	■			■	
G / 10		■	■				
H / 9		■	■				
I / 10	■	■					
J / 9					■		
K / 8					■		
L / 5				■	■		■
M / 9				■	■		■

FLEA 1: Bulk Supply (Low cost)
FLEA 2: Heat Shrinking Technology (CE Certificated and Low Cost)
FLEA 3: Heat Shrinking Technology (Ease of use)
FLEA 4: Field Liner Material, Preservative Resistance
FLEA 5: Robustness of LDPE Outer Sleeve
FLEA 6: Field Liner Material, Adaptability in Shrinkage
FLEA 7: Field Liner Material, Resistance to UV and Microbiological Degrade

Cumulative requirements of treaters and end-users:


Field Liner Engineering Aspects (FLEA) / Pole/Post Treater Requirements


Field Liner Engineering Aspects (FLEA) / End-User Requirements

FLEA 1: Bulk Supply (Low cost)
FLEA 2: Heat Shrinking Technology (CE Certificated and Low Cost)
FLEA 3: Heat Shrinking Technology (Ease of use)
FLEA 4: Field Liner Material, Preservative Resistance
FLEA 5: Robustness of LDPE Outer Sleeve
FLEA 6: Field Liner Material, Adaptability in Shrinkage
FLEA 7: Field Liner Material, Resistance to UV and Microbiological Degrade

4.3. Field Liner Efficacy Testing with Treated Timber: Laboratory Model Systems for Accelerated Assessment.

4.3.1. Field Liner Efficacy in Reducing Leaching of Preservative Components to the Environment.

Collections and chemical analysis of leachate, soil and treated timber samples was not completed within the timescale of the project.

4.3.2. Field Liner Efficacy in Reducing Decay of Treated Timber.

Table 1 displays mean weight losses and soft rot scores for stakes (untreated and treated) removed from the accelerated decay test beds after 6 months exposure. Results for 12 months exposure were not completed within the timescale of the project.

Table 1
Mean % weight losses and Soft-rot scores of variously treated Timber Stakes Exposed to a Fungal Cellar Environment for 6 months

Timber	Treatment	Mean weight loss at 6 months(%)	Mean Soft-rot scores at 6 months
Sitka spruce	CCA / Oo	+0.28 (0.46)	0
Sitka spruce	CCA / OB	-0.18 (0.63)	0
Sitka spruce	CCA / X	-0.44 (0.93)	0
Scots pine	Creosote / OI	-0.66 (1.27)	0
Scots pine	Creosote / X	+2.54 (0.29)	0
Sitka spruce	Azole1 / Oo	-0.66 (0.55)	0
Sitka spruce	Azole1 / OB	-1.29 (0.34)	0
Sitka spruce	Azole1 / X	+1.14 (0.55)	3 (0)
Sitka spruce	Azole2 / Oo	+0.21 (0.67)	0
Sitka spruce	Azole2 / OB	+0.10 (0.13)	0
Sitka spruce	Azole2 / X	+1.65 (0.20)	1 (0)
Sitka spruce	Untreated Oo	+0.94 (0.67)	0
Sitka spruce	Untreated Bo	+1.37 (1.12)	2.33 (1.15)
Sitka spruce	Untreated OB	+1.18 (1.16)	0
Sitka spruce	Untreated X	+4.51 (2.02)	3.33 (1.53)
Scots pine	Untreated Oo	+0.53 (1.16)	0
Scots pine	Untreated Bo	+3.21 (1.93)	0
Scots pine	Untreated OB	+2.97 (1.25)	0
Scots pine	Untreated X	+5.16 (1.29)	1.33 (0.58)

Where:	
Oo	Stakes with an Outer liner only
OB	Stakes with an Outer liner and Bioplast inner liner
OI	Stakes with an Outer liner and a polypropylene inner liner
Bo	Stakes with a bioplast inner liner only
X	No Field Liner fitted

Note: Significant weight losses were those above 3% (weight losses below this figure can be due to the removal of non-structural elements by non-decay fungi). An objective soft-rot score was established by determining the ease with which a sharp object was able to penetrate the surface of the timbers.

- Sitka spruce treated with CCA: No weight losses or indications of soft-rot was found for any lined and unlined Sitka spruce stakes treated with CCA after 6 months exposure.

- Scots pine treated with creosote (dip): Unlined stakes treated with creosote displayed greater weight losses than lined stakes after 6 months exposure. These differences (on a mean basis) were not significantly different. No soft rot was found in any stakes.

- Sitka spruce treated with Azole 1 (dip): Unlined stakes treated with Azole 1 displayed greater weight losses than lined stakes after 6 months exposure. These differences (on a mean basis) were not significantly different. Soft-rot was recorded for the unlined stakes only.

- Sitka spruce treated with Azole 2 (dip): Unlined stakes treated with Azole 1 displayed greater weight losses than lined stakes after 6 months exposure. These differences (on a mean basis) were not significantly different. Soft-rot was recorded for the unlined stakes only.

- Untreated Sitka spruce: Significant weight losses and soft rot scores were recorded for the unlined stakes after 6 months. Though weight losses were also recorded for the variously lined stakes, these weight losses were not of the same order and only bioplast only stakes also suffered a degree of soft rot. It was noted that the lining of these latter stakes had been torn on insertion into the soil test beds.

- Untreated Scots pine: Significant weight losses and soft rot scores were recorded for the unlined stakes after 6 months. Though weight losses were also recorded for the variously lined stakes, these weight losses were not of the same order (though higher than similarly treated Sitka spruce) and no soft rot symptoms were found in these stakes.

4.4. Field Liner Efficacy Testing with Treated Timber: Field Studies for Assessment.

4.4.1. Field Liner Efficacy in Reducing Leaching of Preservative Components to the Environment (*UK field site*)

Uplifts and chemical analysis of treated timber samples were not completed within the timescale of the project.

4.4.2. Field Liner Efficacy in Reducing Leaching of Preservative Components to the Environment and in Reducing the Effects of Termite Attack (*Guadaloupe field site*)

Uplifts and chemical analysis of treated timber samples and examinations of timbers for termite damage were not completed within the timescale of the project.

5. DISCUSSION

5.1. Field Liner Materials Performance

5.1.1. Background.

The chosen Field Liner material was Low Density Polyethylene (LDPE). A typical polyethylene molecule can be represented as a long chain of carbon atoms linked to each other, each carbon atom also being linked to two hydrogen atoms:

$$— CH_2 — CH_2 — CH_2 \text{---------} CH_2 — CH_2 — CH_2 —$$

For clarity, the carbon chain has been shown as straight, but it must be remembered that in fact it is not straight and has a zig-zag configuration in one plane, the hydrogen atoms being arranged above and below the carbon atoms. The chains can be arranged in a completely random fashion, which is said to be an amorphous state or the chains can participate in ordered arrangements or crystals. In reality plastics such as LDPE contain areas that are both amorphous and crystalline with the degree of crystallinity depending upon several factors, such as entanglement, chain size, temperature and branching (Ogorkiewicz, 1970). The similarity in structure of the individual molecules (CH_2) makes possible the close packing of parts of the chains thus giving ordered or crystalline regions. Because of chain entanglement and the presence of branches (every 25-100 chain carbon atoms), LDPE contains unordered amorphous regions. The greater the number of branches the smaller the degree of crystallinity. In general, the crystallinity of LDPE lies in the range 55-70%.

At low temperature the molecules behave like a large number of rigid rods joined together, The overall shape of the molecule being determined by van der Waals forces and molecular entanglement. As the temperature is increased, the thermal energy in the molecules increases and individual atoms oscillate with greater amplitude. If the temperature is increased further these vibrations become large enough to overcome the restricting intermolecular forces and the shape of the molecules can then change in response to an applied stress. At temperatures above this transition region, the thermal energy is so large that the forces restricting changes in shape become very small and the stiffness falls to very low level. Polyethylene has one transition around 110°C, and another around 0°C, but it does not become liquid until above its main transition, the crystalline melting point, at 110 - 130°C. The whole molecule becomes substantially free, only at this point, but even then the chain entanglements render the material 'rubbery'.

On heating LDPE to close to its crystalline melting point, energy is imparted to the molecules and allows them to move relative to each other. At this stage the ratio of crystalline to amorphous regions decreases sharply (Ogorkiewicz, 1970). Upon cooling, the molecular chains are no longer able to move freely and they take on a configuration that allows them to ‘fit’ more closely together and causes the material to shrink.

5.1.2. Impact resistance.

The results for impact resistance show that the processing and weathering of the Field Liner have a positive effect - the impact resistance is increased with the greatest increase occurring in the heat shrunk only samples. The increased impact resistance in the frozen samples may be because the decreased temperature that the plastic was subjected to has reduced the ability of some of the molecule chains to move. This may cause the molecular chains to become stiffer and so increase their ability to resist breaking and may increase the degree of crystallinity of the material. In the heat shrunk only samples and the heat shrunk and frozen samples, heat shrinking has caused the material to become thicker and so this alone may account for the increased impact resistance.

It is therefore evident that the heat shrinking method of Field Liner application followed by the environmental conditions to which the Field Liner will be exposed (on treated timber) will not result in a reduction of the impact resistance of the Liner material.

5.1.3. Tear resistance.

The vertical tearing resistance is unaffected by heat shrinking and only slightly reduced by freezing alone. Freezing of heat shrunk material however significantly decreases the vertical tearing resistance. It is difficult to explain the effects that are occurring in these samples. The rearrangement of the molecules on heat shrinking still impart the same vertical tear resistance on the material implying that there has been no increase in the degree of crystallinity of the material. Freezing of material that has not been shrunk is only slightly effected. It may be that the freezing reduces the movement of the molecule chains making it easier to pull them apart upon tearing. This possible effect appears to be greatly exaggerated in the heat shrunk samples.

There is no effect on the horizontal tearing resistance by heat shrinking or by freezing. This suggests that there is little or no modification of the structure of LDPE by heating or freezing in this orientation.

The heat shrinking method of Field Liner application followed by the environmental conditions to which the Field Liner will be exposed (on treated timber) will result in a reduction in the tearing resistance of the Liner material (in the vertical orientation).

5.1.4. Abrasion resistance.

The abrasion resistance of the material was unaffected by heat shrinking and freezing. In the heat shrunk and frozen samples the abrasion resistance is increased. This shows that the abrasion resistance of the material is only effected by freezing once it has undergone the molecular chain rearrangements that take place on heat shrinking.

The heat shrinking method of Field Liner application followed by the environmental conditions to which the Field Liner will be exposed (on treated timber) will result in an increase in the abrasion resistance of the Liner material.

5.1.5. Testing Preservative Compatibility with Field Liner Material.

Field Liner / standard preservative compatibility test results (creosote and CCA) clearly show that Field Liner material applied to poles treated with these preservatives are unlikely to show any significant degrade over the lifetime of the product. Note that the preservative concentrations used were many orders of magnitude higher than those the Field Liner will come into contact with in service.

5.2. Field Liner Market Requirements

5.2.1. Market Acceptance Tests.

The outcomes of market acceptance discussions to gauge the requirements/preferences of Fence post treaters/producers, Vineyard pole end-users, Utility pole treaters/producers and Utility pole end-users (utility companies) were as follows:

Cumulative requirements of treaters and end-users (top 4):

- Treaters

Heat Shrinking Technology (Ease of use)	8
Field Liner Material, Preservative Resistance	8
Robustness of LDPE Outer Sleeve	10
Field Liner Material, Resistance to UV and Microbiological Degrade	6

- End-users

Heat Shrinking Technology (CE Certificated and Low Cost)	5
Field Liner Material, Preservative Resistance	5
Robustness of LDPE Outer Sleeve	7
Field Liner Material, Resistance to UV and Microbiological Degrade	7

That aspect of the Field Liner of most concern to both treaters and end-users is robustness of the outer sleeve. Clearly this feature of the product is of interest to both in terms of damage in application and use, either of which would severely reduce the efficacy of the product. The excellent results for Field Liner materials performance testing (section 5.1) show that this general concern is likely to enhance the marketability of the product.

Of equal importance to the end-user is resistance to UV and microbial degrade (the latter being of prime concern as UV damage is not an issue for below ground areas where the effects of the Field Liner will be significant). As LDPE material is known to be highly non-degradable by biological means this issue is also likely to support the marketing and acceptability of the product.

Ease of use of the heat shrinking technology and preservative resistance of the Field Liner, are also of high importance to treaters (as is the latter to end-users). Clearly the former is related to throughput of product (lined treated timbers) and the latter again an issue specifically related to product efficacy. Both these issues have been dealt with satisfactorily within this project (section 3.3 and section 5.1.5 respectively) though it is clear that the application apparatus requires further development for CE certification. CE certification is another important concern of end-users and this is related to worker safety for in-situ fitting of Field Liners in the field.

5.3. Field Liner Efficacy Testing with Treated Timber: Laboratory Model Systems for Accelerated Assessment.

5.3.1. Field Liner Efficacy in Reducing Leaching of Preservative Components to the Environment.

Collections and chemical analysis of leachate, soil and treated timber samples was not completed within the timescale of the project.

5.3.2. Field Liner Efficacy in Reducing Decay of Treated Timber.

The results of the accelerated decay test (up to 6 months) (section 4.3.2) show that the highest mean % weight losses occurred in untreated Scots pine and Sitka spruce stakes with no FL attached (5.16 and 4.51% respectively). Measured mean % weight losses were also recorded for untreated Scots pine and Sitka spruce stakes that had bioplast only and an outer liner with a bioplast inner. These were generally below 3%, with the exception of Scots pine with biopast only, which was only just above 3%. In the case of the Sitka spruce stakes with bioplast only, soft-rot fungi had also been able to gain access to the wood. This may be due to the fact that the bioplast on these latter stakes had been damaged on placement thereby reducing the barrier effect to soft rot organisms. This was not the case with the bioplast only Scots pine stakes. Clearly, in this case the bioplast was forming a tight enough sleeve to form a barrier to prevent access to the decay fungi.

In all the other stakes minor weight losses or gains were recorded. These results strongly indicate that a combination of the Field Liner and wood preservative treatments is preventing decay by soft-rot fungi. This was confirmed by 12-month decay results, though these figures are not presented here as 12-month stake uplifts were not undertaken within the timescale of this project.

Soft-rot scores were highest in the untreated Sitka spruce stakes with no Field Liner (3.33). This correlates well with the mean weight loss figure for these stakes. The next highest mean soft-rot score was in the Azole 1 treatment with no Field Liner (3). However this did not correlate with any significant weight loss. It is likely that the initial presence of soft-rot decay had not provided any significant weight loss up to the 6-month period. The unlined untreated Scots pine samples had the highest % weight loss but a low mean soft-rot score. This is may due to the fact that the density of Scots pine (~540 kg/m^3) is greater than that of Sitka spruce (~440 kg/m^3) (Desch and Dinwoodie, 1981) making it more difficult to detect the subtle changes caused by weight losses of between 4-5%. This means that the Scots pine is naturally harder and any knife test will reflected this. The Azole 2 treatment with no FL had the lowest recorded soft-rot score and this again correlated with no significant weight loss. This clearly represents an early stage of soft-rot attack which has had no significant effect on the weight loss in the stakes at this stage.

No other stakes showed any signs of soft-rot decay using the knife test scoring system, which shows that the Field Liner material and preservative treatments were actively preventing soft-rot decay at this stage of the study. The Field Liner material may also be preventing soft-rot decay from occurring in those untreated stakes in which no soft-rot score was recorded.

Mould growth most frequently occurred in those lined stakes that were untreated showing the combination of the Field Liner material and wood preservatives was preventing invasion by mould fungi. The two exceptions to this were the creosote dip treatment where the mould growth recorded was present above the groundline level and this was a pure culture of ***Cladosporium resinae***. This fungus is the most frequently isolated from creosote treated distribution poles (Wang and Zabel, 1990. Bruce, 1983). The other exception was one of the Azole 1 stakes. Mould growth probably occurred in this stake because upon examination the liner material was seen to be split along its whole length at several places. These splits may be due to the wood expanding due to water uptake or it may be the result of a manufacturing defect. The mould growth recorded on other stakes was ***Trichoderma*** spp. An unidentified growth that produced red staining on the stakes was also recorded. These growths were seen as both individual and mixed cultures on some stakes.

The indications of the efficacy of the Field Liner material in preventing symptoms of decay and mould growth (on treated stakes) were confirmed by the 12-month results which were not completed within the timescale of this project.

5.4. Field Liner Efficacy Testing with Treated Timber: Field Studies for Assessment.

5.4.1. Field Liner Efficacy in Reducing Leaching of Preservative Components to the Environment (*UK field site*)

Uplifts and chemical analysis of treated timber samples were not completed within the timescale of the project.

5.4.2. Field Liner Efficacy in Reducing Leaching of Preservative Components to the Environment and in Reducing the Effects of Termite Attack (*Guadaloupe field site*)

Uplifts and chemical analysis of treated timber samples and examinations of timbers for termite damage were not completed within the timescale of the project.

6. CONCLUSIONS

- The practicability of basic heat-shrink apparatus for application of Field Liners to treated timbers (for ground contact use), for domestic/retail, field-scale and industrial-scale markets, has been proved.

- The excellent performance of the chosen LDPE Field Liner material, in terms of adaptation to heat-shrinking, environmental exposure (common to exterior timbers), has been proved.

- The excellent performance of the chosen LDPE Field Liner material, in terms of resistance to the corrosive effects of standard Hazard Class 4 European CCA and creosote wood preservatives has been demonstrated.

- Based on market acceptance tests it is clear that the Field Liner product and concept requires little modification in order to enter the European market place as a viable product.

- Early indications from laboratory efficacy testing show that the Field Liner product will enhance the decay resistance of standard preservatives (cresote and CCA). This will result in a longer service life for preservative treated timber for exterior use. *Note that this conclusion is supported by later findings from studies not completed within the timescale of this project.*

- Early indications from laboratory efficacy testing show that the Field Liner product will enhance the decay resistance of Hazard Class 3 preservatives. This should permit present Hazard Class 3 preservatives (with improved environmental profiles) to challenge more environmentally damaging preservatives (e.g. CCA and creosote) for the Hazard Class 4 market (exterior timber in ground contact) will result in a longer service life for preservative treated timber for exterior use. *Note that this conclusion is supported by later findings from studies not completed within the timescale of this project.*

NB: Other conclusions, such as the excellent Termite efficacy of the Field Liner product were not included in the above list as these results were not completed within the timescale of the project.

7. TECHNOLOGY IMPLEMENTATION PLAN

This project has not been completed within this final reporting period. Therefore a detailed technology implementation plan cannot be developed. Questions asked in the standard reporting template are reproduced below with answers as far as is known at present.

- **What are the benefits arising from the project in real socio-economic terms?**

The benefits outlined in section 8 of the original project proposal remain current. The most important of these are:

a) prolonging the service life of preservative treated poles in service thus reducing environmental impact
b) creating an additional product leading to potential employment opportunities without displacement

- **Which socio-economic/industrial sectors are considered to be the main beneficiaries?**

Socio-economic group:
Rural landowners and users
Industry:
Forestry / forest products industry
Plastics manufacturing industry

- **How do you plan to approach this target audience?**

Advertising materials for any resulting products will explain the benefits for these socio-economic / industrial sectors.

- **Means of dissemination and exploitation; patents, publications, conferences, demonstration.**

The main means of dissemination will be through the SME partners actually launching products arising from the project. Existing patents have been maintained and are presently under discussion by the SME partners. Industry and potential customers have been involved in the demonstration / customer feedback aspects of the project.

- **What is the nature and the amount of additional investments required to promote or make full-use of the project's achieved results?**

The SME partners are now very near market and need to agree appropriate territorial and sectoral approaches to the market. This will inform their investment needs. It is unlikely that further public sector funding beyond this project will be required. However, the cost of maintaining and defending patents remains a challenge if sufficient sales are not generated to cover such costs.

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