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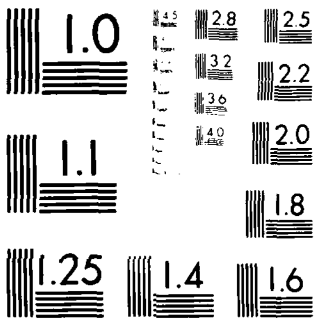

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TECOM Project No. 7-CO-RDO-TT1-003
USATTC Report No. 840911

METHODOLOGY INVESTIGATION

DATA REPORT

NATURAL EXPOSURE vs CHAMBER SIMULATION

by

GEORGE F. DOWNS III, P.E.

Materiel Test Division

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8 NOV 1984

SUBJECT: Methodology Investigation Data Report, Natural Exposure vs. Chamber Simulation, TECOM Project No. 7-CO-RDO-TT1-003

Commander
US Army Tropic Test Center
ATTN: STETC-MTD-P
APO Miami 34004

Subject report is approved.

FOR THE COMMANDER:

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The word "he," when used in this report, represents both the masculine and feminine genders, unless otherwise specifically stated.

Units presented in this report are the customary units in which material properties were specified by applicable documents, or units in which the measurements were made. It is felt that additional conversions would add confusion and degrade the accuracy of data presented, without serving any useful purpose.

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This data report presents the results of the first phase of a methodology investigation intended to increase the validity of the environmental chamber testing of Army materiel. This phase involved field exposing material samples in selected natural tropic environments in the Republic of Panama and testing those samples to document changes which occurred as a result of that exposure. Subsequent phases will be conducted in environmental chambers at the Electronic Proving Ground, Fort Huachuca, Arizona, to attempt to duplicate these changes.

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FOREWORD

This acknowledges the efforts of the following persons who contributed in a major way to the preparation of sites, emplacement/retrieval and testing of samples, identification of fungi and collection/tabulation of data: William C. Peart, Vielka Quintero, Bolivar Roman, and Antonio Gressel.

SECTION 1. SUMMARY

1.1 INTRODUCTION

This US Army Tropic Test Center (USATTC) data report presents the results of the first phase of a methodology investigation intended to increase the validity of the environmental chamber testing of Army materiel. This phase involved field exposing material samples in selected natural tropic environments in the Republic of Panama and testing those samples to document changes which occurred as a result of that exposure. Subsequent phases will be conducted in environmental chambers at the Electronic Proving Ground, Fort Huachuca, Arizona, to attempt to duplicate those changes.

1.2 BACKGROUND

a. Over the years, substantial amounts of time and money have been spent on attempts to devise laboratory environmental tests that will correlate with natural environments in terms of effects produced on materials and equipment. Some studies have claimed success to a limited degree; however, these were only for specific test specimens for given times and places. Other studies have reported no direct relationship. Three recent studies[1] have attacked this problem by exposing items of equipment and measuring performance as an indication of deterioration. Some of the problems involved in this approach included excessive sensitivity to small amounts of deterioration of certain components and insensitivity to massive structural deterioration. This investigation attempts to simplify the analysis of deterioration by using basic, simple materials whose deterioration can be easily measured by straightforward tests over a wide range of deterioration.

b. The environmental tests specified by MIL-STD-810D include separate tests for solar radiation, humidity, fungus, and other environmental forcing functions. Each of these tests is designed to duplicate the nature of the forcing function so that the item under test will receive as realistic a treatment as possible. Problems exist with the "treatment duplication" approach because of the following implicit assumptions:

(1) A single forcing function is responsible for the majority of environmental effects suffered by an item.

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[1] Exposure/Performance Tests of Selected Materiel Items, Downs, G. F. and Gorak, R. J., USATTC Report 790102, January 1979

Chamber vs Environmental Deterioration Tests, Dement, Wm. A. and Calderon, O.H., USATTC Report 781201, January 1979

Comparison of Effects of Natural Tropic Environment vs Chamber Exposure on Army Materiel, Ivankoe, M. Jr. and Askin, D., USARDC Report ARPAD-TR-83006, June 1984

(2) By simulating a particular forcing function, we can determine the item's resistance to the environment in which that forcing function predominates.

(3) If more than one environmental forcing function is involved, we can test for resistance (or sensitivity) to them individually.

c. These assumptions make simulated environmental testing much easier but unfortunately they gloss over the synergism that occurs when two or more environmental forcing functions are active at once. The intensity of the forcing function may be unrealistically high, low, or continuous. The order of attack by successive forcing functions may be incorrect, so that an item or material is not susceptible to a particular forcing function at the time it is presented, but might be after attack by another forcing function. Furthermore, the exposure environments are so complex that the individual forcing functions can only be expressed in general terms and only roughly approximated. Thus the predictive validity of current chamber test methods is hampered by the fact that the chamber tests generally result in deterioration patterns that do not duplicate or simulate the deteriorative effects observed in natural environmental exposures. Since the chamber test effects have not corresponded to natural exposure effects, the severity of effects and duration of exposure are questionable at best. For these reasons this investigation uses the "effects duplication" approach, rather than "treatment duplication".

1.3 OBJECTIVE (USATTC Portion Only)

The objective of this portion of the investigation is to provide a data base of natural environmental effects on the sample materials so that chamber tests will have a "target" set of effects to attempt to duplicate or at least approximate.

1.4 GOALS OF INVESTIGATION

a. Determine valid intensity, duration, and cycling of environmental forcing functions in existing single-chamber tests. This will be accomplished by manipulating chamber controls to approximate, as closely as possible, the environmental effects observed in this natural tropic exposure portion of the investigation. The forcing function levels and timing will be adjusted to provide the most rapid deterioration possible, consistent with maintaining the same deterioration mechanisms observed in natural tropic exposures. Update MIL-STD-810D chamber test methods to provide more reliable tropic service predictions for items tested in the laboratory. This is a short-term (2-year) test methodology improvement goal.

b. Develop dual environmental function tests (DEFT) that will present several different environmental forcing functions to an item in a chamber in order to provide meaningful, realistic accelerated test methods that will reproduce natural environmental effects. This is a long-term research goal.

1.5 SUMMARY OF PROCEDURES

Samples of bare and galvanized steel wire, insulated copper wire, nylon, polypropylene and cotton twine; glass plates and printed circuit boards were exposed for periods of up to a year in open field and forested sites near the Caribbean coast of the Republic of Panama. Samples were retrieved monthly and subjected to laboratory testing. Details of test methods are presented in Section 2 of this report.

1.6 SUMMARY OF RESULTS

Results of this portion of the project are so voluminous and varied as to be virtually impossible to summarize numerically. The following concise statement can be made: A data base of tropic deterioration of a variety of common materials was generated in order to continue the investigation of chamber testing to achieve effects as similar as possible. Although most of the materials behaved approximately as expected, glass, insulated wire, and galvanized steel wire deteriorated less than expected and did not yield any trends that could be considered permanent effects. Nonetheless, these materials may be useful in developing tests of greater severity than was experienced in our exposure environments in the one-year exposure period.

1.7 ANALYSIS

A detailed analysis of results obtained to date may be found in the analysis and discussion of results portion of Section 2 of this report. Since this report is a data report on the first phase (natural exposure) of the project, an overall analysis is not appropriate at this point.

1.8 CONCLUSIONS

The objective of this portion of the investigation was met. A data base of natural environmental exposure effects is presented in this report.

1.9 RECOMMENDATIONS

It is recommended that the chamber portion of this project be funded and performed in order to obtain the benefits from this initial natural exposure phase. Detailed recommendations concerning chamber testing will be found in Section 2 of this report.

SECTION 2. DETAILS OF INVESTIGATION

2.1 SAMPLE MATERIALS

The following sample materials were used in this investigation:

a. Wire, 0.028 inch, zinc coated, NSN 9505 00 248 9847 Label information: Wire, nonelectrical, steel, carbon, round, 0.028 inch diameter, 478.2 ft/lb, 1 lb spool, specification QQ-W-461H/c, 2/81, type 1010, temper S, finish 5, class 1 DLA500-81-UI23 Modern International Corporation, Long Island City, NY 11106

b. Wire, 0.029, bare steel, NSN 9505 00 294 7893 Label information: Wire, steel, carbon, round, 0.0286 inch diameter, 458.4 ft/lb, 5 lb coil, 1010 steel, annealed condition, finish 1, 70,000 PSI max, 15% elongation min, specification QQ-W-461G/a 10/73 DSA500-73-M-QK46. (Note: This wire had a black coating which was not strippable using ordinary laboratory solvents. It was removed by heating the entire coil to approximately 900 degrees F. and cleaning with steel wool.)

c. Wire, copper, insulated, 20 gage, NSN 6145 00 482 9550 Label information: Wire, copper, tinned, insulated, AWG 20-7, type L W color 9.0.4.5, Customer P.K087, 500 ft spool, specification MIL-W-76B DLA500-82, National Wire & Cable Corporation, 136 San Fernando Road, Los Angeles 31, CA

d. Nylon twine, waxed, NSN 4020 00 954 1118 Label information: Twine, fibrous, nylon, MIL-T-713E-Natural, type P, class 1, waxed. 1 lb. Actual denier after dewaxing: 5600 DLA500-79-M-MD23, Western Filament, Inc., Glendale, CA 91204

e. Twine, cotton, size 18, NSN 4020 00 243 3152 Label information: Twine, cotton, cable laid, 6 ply, 3 strand, size 18, specification T-T-881, type 1, 1020 ft/lb, 1 lb ball, 35 lb minimum breaking strength. Calculated denier: 13139, actual denier 14211

f. Twine, Polypropylene, natural (unpigmented) Label information: Tytite Poly twine, size 425/1, random size packages, approximately 10 lbs/ball, calculated denier (based on 425 ft/lb) 31,509 actual deniers 31,069 and 33,370. Advertised breaking strength 285 lbs. Blue Mountain Industries, A Carlsbrook Company, Blue Mountain, AL 36201

g. Twine, Polypropylene, black Label information: Tytite Poly Twine, size 425/1, random size packages, approximately 10 lbs/ball, calculated denier (based on 425 ft/lb) 31,509 actual denier 35940. Advertised breaking strength 285 lbs, Blue Mountain Industries, A Carlsbrook Company, Blue Mountain, AL 36201

h. Printed circuit boards-Vector Circbord p/n 8002 Label information: Vector Electronic Co., Inc, 12460 Gladstone Avenue, Sylmar, CA 91342 P/N 8002 2 buses and bare other side 4 1/2 x 6 1/2 x 0.062 thick, FR4 epoxy glass composite (C.E.M.) laminate, clad with 2 oz. (0.0027 inch thick) copper, bright tin plated. Holes 0.042 inch diameter on 0.1 inch grid. Lot numbers 2921 L1 (18) and 3431 A2 (12) were used. Lot 2921 L1 was solid blue, while lot 3431 A2 had a light-colored layer in the center. The manufacturer stated that both were Epoxy fiberglass material but the base stock for the latter lot number is made by a different manufacturer to the same specification. For ease of connection to test equipment, holes at positions 2/58 and 39/58 were drilled out to approximately 0.100 inch (2.5 mm).

i. Glass plates: Commercial window glass 0.188 inch thick, nominally 4 x 6 inches, typically 3.950 x 5.915 inches.

j. Wood samples: Samples were milled from wirebound ammunition box boards of red gum, *Liquidamber styraciflua*, approximately 5/16 - 3/8 inch thick, in the form of ASTM D638 tensile bars. The reduced section was 0.495 - 0.505 inch wide. The varying thickness was taken into account in testing. The samples were mounted on 4 x 12 inch acrylic panels 1/4 inch thick with a 3 x 6 inch rectangular hole in the center to allow for drainage of water and ventilation. The samples were mounted on edge, seven to a panel, secured to the panel with nylon twine and separated from each other by phenolic washers, to allow for drainage and ventilation.

2.2 SELECTION OF EXPOSURE SITES

Exposure sites for this project were chosen to obtain maximum information on natural tropic deterioration from rainfall, humidity, fungi and sunlight, and to attempt to distinguish between these parameters if possible. The following sites were chosen for the associated reasons:

a. Fort Sherman Open Site (Open Sunfield): chosen for maximum incidence of solar radiation (insolation), high humidity and rainfall. Referred to in this report as "Open site" or "FSO".

b. Fort Sherman Forest Site (Skunk Hollow): Chosen for maximum rainfall, high humidity, abundant fungi, limited insolation. Referred to in this report as "Skunk Hollow" or "SH".

c. Fort Sherman Forest Site, Hut (Skunk Hollow Hut): chosen for abundant fungi, high humidity, no rainfall and no insolation. Referred to in this report as "Hut".

d. McKenzie Forest Site: chosen for heavy rainfall, high humidity, abundant fungi and limited insolation. Also for comparison with Skunk Hollow. Referred to in this report as "McKenzie" or "McK". The term "Forested Sites" in this report refers to both Skunk Hollow and McKenzie forest sites but not to the Hut unless specifically stated.

e. Control: Control/Baseline samples were kept in cabinets or boxes in a dark, air-conditioned environment. In tabulated data in this report, values for month "0" are mean values of control samples.

2.3 BRIEF DESCRIPTION OF SITES

2.3.1 Fort Sherman Open Site

This site has been used for many years for studies of actinic deterioration and other tropic effects. It is located at UTM coordinates 143346, about 500 meters from the Caribbean Sea. The water table varies from about one foot depth to slightly above ground level insuring high humidity. Nearby forested areas provide an abundance of fungal spores. Sunlight and rainfall are among the highest of USATTC's available open sites.

2.3.2 McKenzie Forest Site

This site is located on the grounds of Battery McKenzie, an abandoned World War II coast artillery position at Fort Sherman. It was established as an exposure site in 1978. It is about 800 meters inland from the Caribbean Sea in a tropic, moist forest at UTM grid coordinates 111319.

2.3.3 Fort Sherman Forest Site (Skunk Hollow)

This site has also been in use for approximately 40 years and is considered one of the most ideal places to study tropic deterioration, particularly fungal and humidity effects. It is located in a band of unusually heavy rainfall, about one kilometer from the Caribbean Sea at UTM coordinates 146312. It is surrounded by hills which keeps the wind and atmospheric salt very low and the humidity high. The exposure racks are located in an area which is in moderately dense shade most of the day. The hut is also located in a relatively shady area. It is covered with corrugated metal for the roof and walls, with approximately one foot at the top and bottom of the walls covered with 1/2 inch mesh expanded metal, to allow good ventilation. With the door closed the interior of the hut is relatively dark and contributions of ultraviolet to deterioration are effectively eliminated. There is sufficient roof overhang so that no rain enters the hut, but humidity remains high and a wide variety of particulates settle on the samples.

2.3.4 Meteorological Data for Sites

The following five tables give meteorological data for the sites used in this study. Where actual data were not available, typical historical data for periods of similar rainfall are presented. "Months" refer to the periods shown in the exposure schedules in paragraph 2.5.

TABLE 1. TEMPERATURE DATA
(degrees Fahrenheit)

	Ft. Sherman Open			McKenzie			Skunk Hollow*			Hut*		
Month	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
1	81.8	78.6	86.9	79.8	76.7	83.9	77.0	73.4	80.6	77.0	75.2	80.6
2	81.6	76.7	88.2	78.2	74.2	85.6	75.2	73.4	78.8	75.2	73.4	78.8
3	81.5	76.9	86.9	79.2	73.2	80.5	75.2	73.4	78.8	75.2	75.2	78.8
4	81.7	79.3	86.3	79.5	75.9	82.3	78.8	77.0	80.6	75.2	73.4	78.8
5	79.6	75.5	82.2	77.9	74.9	81.7	75.2	73.4	78.8	77.0	75.2	80.6
6	78.5	74.3	84.4	79.2	75.9	83.1	75.2	73.4	78.8	77.0	75.2	80.6
7	80.0	76.5	85.6	78.8	76.1	82.4	78.8	75.2	80.6	77.0	75.2	80.6
8	79.0	75.5	84.4	77.9	77.9	81.4	78.8	75.2	80.6	77.0	75.2	80.6
9	77.7	77.3	84.8	77.4	74.6	81.8	78.8	75.2	82.4	77.0	75.2	80.6
10	81.1	78.0	85.5	79.3	75.9	83.8	80.6	77.0	84.2	77.0	75.2	80.6
11	81.3	77.8	86.4	79.8	76.5	81.5	78.8	75.2	82.4	75.2	73.4	78.8
12	81.7	76.7	87.5	80.0	75.9	85.9	78.8	75.2	84.2	80.6	78.8	84.2

*NOTE: Values for Skunk Hollow and Hut are estimates based on historical data for months of similar rainfall.

TABLE 2. RELATIVE HUMIDITY DATA
(percent)

	Ft. Sherman Open			McKenzie			Skunk Hollow*			Hut*		
Month	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
1	87	76	96	87	79	93	98	92	100	98	89	100
2	96	75	99	91	82	95	97	89	99	95	85	98
3	89	76	98	89	85	95	97	91	100	97	89	100
4	88	77	99	92	84	96	97	89	100	97	89	100
5	92	79	99	93	92	100	99	93	100	96	84	100
6	92	78	99	97	90	100	99	93	100	96	84	100
7	92	79	99	98	93	100	96	84	99	96	84	100
8	91	80	98	94	88	100	97	94	100	94	87	99
9	83	74	92	92	80	99	84	74	94	87	75	95
10	81	72	91	92	82	99	88	71	99	89	72	99
11	83	72	91	83	74	97	83	73	93	84	72	94
12	81	68	93	90	73	99	92	78	99	86	72	95

*NOTE: Values for Skunk Hollow and Hut are estimates based on historical data for months of similar rainfall.

TABLE 3. RAINFALL
(inches)

Month	Ft. Sherman Open		McKenzie		Skunk Hollow	
	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative
1	25.07	25.07	25.82	25.82	24.60	24.60
2	12.78	37.85	13.88	39.70	13.43	38.03
3	10.44	48.29	18.79	58.49	12.78	50.81
4	15.21	63.50	15.13	73.62	16.05	66.86
5	11.48	74.98	12.95	86.57	12.44	79.30
6	20.72	95.70	16.85	103.42	17.08	96.38
7	20.68	116.38	12.14	115.56	16.71	113.09
8	25.28	141.66	28.43	143.99	29.66	142.75
9	2.82	144.48	4.70	148.69	2.88	145.63
10	1.54	146.02	2.33	151.02	3.20	148.83
11	1.68	147.70	2.17	153.19	0.72	149.55
12	1.22	148.92	1.65	154.84	1.94	151.49

TABLE 4. SOLAR RADIATION AT FT. SHERMAN OPEN SITE
(langleys)

Month	Per Month	Cumulative
1	11,174	11,174
2	12,468	23,642
3	10,869	34,511
4	12,292	46,803
5	10,865	57,688
6	11,662	69,330
7	11,119	80,449
8	9,105	89,554
9	12,264	101,818
10	13,904	115,722
11	17,638	133,360
12	15,325	148,685

TABLE 5. ATMOSPHERIC SALTFALL DATA
(milligrams of chloride per square meter)

	Ft. Sherman Open		McKenzie		Skunk Hollow	
Month	Per Day	Cumulative	Per Day	Cumulative	Per Day	Cumulative
1	31.23	999.4	1.89	62.4	2.94	97.0
2	26.22	1943.3	3.08	173.3	2.89	201.1
3	6.20	2135.5	1.16	208.0	1.23	235.5
4	18.09	2732.5	0.63	228.8	1.06	249.3
5	13.01	------	1.45	-----	2.67	353.4
6	13.01	3356.9	1.45	298.4	6.03	492.1
7	4.68	3553.5	1.74	350.6	1.74	546.0
8	5.00*	3713.5	1.45*	395.6	1.45*	591.0
9	10.05*	4045.1	1.28	444.2	1.10	632.8
10	29.55	4961.2	2.24	513.7	3.36	737.0
11	38.43	6191.0	5.24	681.4	3.93	862.7
12	46.47	7352.7	14.24	1108.6	13.41	1265.0

* Indicates an estimate based on historical data

2.4 EXPOSURE MODES

At all field sites, except the Hut, the samples were exposed on racks supported on ceramic insulators. The racks were inclined 30 degrees from the horizontal, with the low side facing east. Since it is overcast more frequently in the afternoon, this insures optimum insolation consistent with good drainage of rainwater. In the Hut, cordage and wire samples were hung vertically from ceramic insulators, and the other materials were exposed on a rack lying flat on a shelf, fabricated from 1/2 inch mesh expanded metal, about four feet high.

2.5 EXPOSURE SCHEDULES

All samples were exposed on April 25, 1983, and retrieved on either the 25th of subsequent months, or the first working day after the 25th. The actual dates were as follows:

Exposure	25 April	83
Retrieval	25 May	83
" "	25 June	83
" "	25 July	83
" "	25 August	83
" "	25 September	83
" "	25 October	83
" "	28 November	83
" "	27 December	83
" "	25 January	84
" "	23 February	84
" "	26 March	84
Final Retrieval	25 April	84

2.6 TEST METHODS

a. General. All mechanical testing was done on an Instron model 1125 universal testing machine with a Microcon processor. The various grips and fixtures used, as well as the particular parameters measured and means of measuring them will be described for each material.

b. Wire, bare and galvanized. Tensile tests were conducted on nominal 3 foot retrieved samples of wire, using a 2 inch gage length and pulling at 0.050 inch per minute. Hydropneumatic grips were used with 2 x 2 inch serrated faces and relatively low gripping pressure, to grip securely but not cause "grip breaks". The highest load experienced during these tests was about 38 pounds, so the 50 pound range was selected. Parameters measured included peak load, yield load (0.02% offset), peak stress, yield stress, and peak elongation (engineering strain). "Flex" correction was used to eliminate sample, grip, and machine slack from elongation readings printed out.

c. Insulated wire. Insulated wire samples were cultured on carrot agar and mineral salts agar to identify the fungi growing on the insulation. They were then tested electrically for insulation leakage, by winding them into a coil and dipping the coil in a saturated solution of salt (sodium chloride) within a bare monel wire cage. The ends of the wire were stripped and connected to one side of an LCR meter and the cage to the other side. Care was exercised to keep the stripped ends above the surface, and not allow them to get wet with the salt water. In cases where they did get wet, they were rinsed with clear water. Resistance was measured at 120 Hertz. Normal resistance for a coil wound from 190 inches of wire was approximately 6 megohms, and it varied inversely with the length of the wire, i.e. for a coil of 100 inches of wire, the resistance would be approximately 11.4 megohms.

In cases where the measured resistance was substantially below normal, the coil was unwound and examined for mechanical damage. All damaged areas were then kept above the surface of the salt solution with the coil rewound. Testing was repeated, and in all cases, the resistance was in the neighborhood of 6 megohms. Following the electrical tests, the wire samples were tested mechanically using the same method and fixtures used for cordage (see below), except the only parameters measured were peak load and peak elongation.

d. Twines. Similar methods were used for cotton, nylon, and polypropylene twines, with the exception of the cotton twine samples, which were cultured on carrot agar and mineral salts agar for identification of fungi growing on the twine. Since the other twines are not generally considered to be affected by fungal growth, they were not cultured, although fungal growth was observed on all twines at some sites. Breaking strength, elongation, and tenacity were measured using the Instron 1125 universal testing machine, with its associated Microcon processor. The method was in basic accordance with ASTM D2256, using grooved capstan grips to minimize the chances of grip breaks. A gage length of 3 inches was selected to optimize the number of tests per sample. A testing speed of 12 inches per minute was used. The Microcon's "flex" correction was used so that measurement of elongation began with loading of the sample, rather than starting the machine. This eliminates errors in elongation due to slack in gripping and tightening of the grips. Linear density was calculated by weighing a two meter sample and multiplying the weight by 4500. (Denier = weight in grams of 9000 meters of sample.) Parameters measured included breaking strength (peak load) in pounds, break elongation (peak strain) in %, and tenacity (peak stress) in grams force per denier. In the case of the polypropylene twines the denier was so great (over 30,000) that the value could not be entered into the Microcon directly so it was divided by 10, resulting in a printout of tenacity that was off by a factor of ten. This was corrected in transcription of the data. Conversions of units were done by the Microcon, so the test results were printed out in the desired units as soon as each test was completed. The Microcon also calculated means and standard deviations for each group of samples.

e. Circuit boards. Circuit boards were tested and re-exposed at each monthly sample retrieval. Because they were usually damp when they arrived at the laboratory, they were laid out on a bench in an air-conditioned room and tested the following morning after drying overnight. Testing was done using a Hewlett-Packard LCR meter, model 4261A or 4262A, with connections made to the two main buses of each board and measurements of apparent capacitance (in picofarads) and resistance (in megohms to a maximum of 20) at frequencies of 120Hz, 1kHz, and 10kHz. (The model 4261A LCR meter could only measure at 120 Hz and 1 kHz and was only used when the 4262A was not available.) Following testing the boards were returned to their exposure racks. After the final exposure period the boards were tested, washed with a weak detergent solution and a typewriter brush to remove salts and organic debris, thoroughly rinsed, dried, and given a final test to determine if any of the observed changes were reversible.

f. Glass plates. Glass plates were exposed to obtain information on adventitious growth of fungi in atmospheric particulates and aerosols deposited on the glass, and also to determine if there would be etching of the glass by fungal metabolites. The plates were retrieved and tested with a photographic densitometer to numerically measure obscuration by deposits and fungal growth. They were then microscopically examined to identify fungi and other materials on the surface. Photomicrographs were taken to document what was observed. Following this, a one inch strip was cleaned on both sides of each end and those areas tested again with the photo densitometer to measure the obscuration of the "dirt". Following this, the plates were re-exposed for another month and the remaining unwashed center section tested and examined the next time. Plates were not re-exposed following the second retrieval. Typically, one previously retrieved plate and one "new" plate were retrieved from each site each month. At the end of the exposure period (one year) all remaining plates were retrieved, examined and tested, followed by chromic acid cleaning to remove all organic debris. The plates were then examined and tested one final time to detect etching or other damage to the glass.

g. Wood samples. All wood samples were measured for thickness and width prior to exposure. Upon monthly retrieval they were weighed, and then reweighed periodically, while being stored in the laboratory, to determine that they had reached moisture equilibrium with the laboratory atmosphere (40-50% RH). Upon reaching moisture equilibrium they were tested in 3-point beam bending over a 6 inch span. Parameters measured included breaking load (peak load) in pounds, deflection (peak elongation) in inches, and a modified modulus of rupture (peak stress) in pounds per square inch. The modulus of rupture was calculated as follows:

$$\text{Modulus of rupture} = \frac{3\ P\ L}{2\ W \times T \times T}$$

In this equation, P = peak load, L = length of span (six inches in this case), W = width of sample (approximately 0.500 inches) and T = the thickness of the sample. In order to get a direct printout of modulus of rupture, a number was calculated for each sample to enter into the Microcon as "area" according to the following:

$$\text{"Area"} = \frac{W \times T \times T}{9}$$

Since the "peak load" is divided by this number to obtain "peak stress", the value printed out for "peak stress" is actually the modulus of rupture in pounds per square inch. Following mechanical testing, small pieces of wood were removed from the fracture surface and cultured on carrot agar and mineral salts agar to identify fungi growing within the wood sample.

2.7 DISCUSSION OF RESULTS FOR ALL MATERIALS AND TESTS

2.7.1 Bare and Galvanized Wire, General

Results for bare wire tensile tests were obtained in values of breaking load (pounds), 0.2% offset yield load (pounds), ultimate tensile strength (pounds per square inch) and 0.2% offset yield strength (pounds per square inch). Yield values were somewhat affected by the work hardening involved in unrolling the wire from the coil in which it was received, emplacing and retrieving samples, and general handling. Since the wire was in the annealed condition, a small amount of handling resulted in sufficient work hardening to obscure minor changes in strength caused by corrosion. Fortunately, a subtantially greater amount of work hardening is involved in stretching the wire to ultimate failure, so breaking loads are essentially unaffected. The change in cross-sectional area due to corrosion was not taken into account in calculating stress values, so that stress data collected are directly proportional to peak load. (For practical purposes the tensile strength of the steel can be considered constant so that the percent reduction in peak load is equal to the reduction in cross sectional area.) For these reasons the data presented will be limited to breaking loads, which are considered to present all of the valid information gained in these tests.

2.7.1.1 Bare Wire

As expected, the Fort Sherman Open site yielded the most consistent decline in breaking load over the exposure period, with total failure at 9 months. Deterioration was also consistent but much slower in the Hut. In the forested sites on racks, the wires experienced about equal corrosion up to 5 months when all of the wires at the McKenzie Forest site failed at the ends where they were wrapped around ceramic insulators. Similar failures occurred at the Skunk Hollow Forest site at 9 months. In an effort to determine the cause of this rapid corrosion at the ends of the wire, rainwater was collected in two vessels, one of which had a pad of clean steel wool in the collection funnel. Phenolic compounds were detected in the water, which have been shown in other studies[2] to greatly accelerate corrosion by complexing with the corrosion product and rendering it water soluble. Thus there is no protection of the underlying surface by an accumulation of corrosion products because they are washed away. The greater the amount of time the sample in question remains wet, the more severe this effect becomes. Samples were exposed to somewhat greater insolation at Skunk Hollow and thus dried somewhat quicker, delaying the failure of the ends of the wires by 4 months. Because the more rapidly corroded ends of the wires were not used as tensile test samples, the nonzero values are considered valid in all cases.

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[2] Corrosion of Steel in a Black Mangrove Environment, Chen, F., and Dement, Wm. A., USATTC Report 821001, October 1982

TABLE 6. BREAKING STRENGTH OF BARE STEEL WIRE SAMPLES (pounds)

Month	FSO	McK	Hut	SH
0	28.83	28.83	28.83	28.83
1	22.30	27.07	28.55	28.09
2	19.17	26.52	28.00	26.31
3	18.73	28.17	28.23	27.68
4	13.25	27.49	27.44	27.70
5	12.90	0	26.42	26.23
6	9.82	0	28.17	24.80
7	10.16	0	25.82	24.03
8	7.71	0	26.32	22.82
9	0	0	27.32	0
10	0	0	24.78	0
11	0	0	22.74	0
12	0	0	NS*	0

*NS = no sample

2.7.1.2 Galvanized Wire

All of the galvanized wire samples tested gave mean values ranging from 39.01 to 40.30 pounds breaking load. This is considered to be the approximate range of experimental error and not an effect of exposure. Confirming this, visual examination of samples retrieved indicated that the galvanize coating was beginning to fail at several sites at the end of the exposure period. The coating contributes nothing to the strength of the wire but effectively preserves the wire by sacrificial action. Therefore, although there was deterioration of the coating over the exposure period, it successfully protected the underlying steel wire so that deterioration could not be measured by changes in tensile strength of the wire. Had the exposure period been somewhat longer, the strength of the wires would probably have begun to drop.

2.7.2 Twines (General)

Tests of twines of various types are useful for separating the effects of the various environmental forcing functions. For example, most polymeric twines are immune to the effects of fungus and nearly immune to moisture. All are affected to varying degrees by ultraviolet radiation, with polypropylene the most affected of the materials used in this study. Cotton is affected by moisture, fungus and ultraviolet radiation, although the ultraviolet radiation inhibits fungal growth. Comments concerning strength of twines refer to both breaking strength and tenacity, since for a given twine they are directly proportional.

TABLE 7. BREAKING STRENGTH OF GALVANIZED STEEL WIRE (pounds)

Month	FSO	McK	Hut	SH
0	39.44	39.44	39.44	39.44
1	39.69	39.74	39.63	39.73
2	39.70	39.70	39.79	39.75
3	40.30	39.85	39.79	39.91
4	39.39	39.74	39.78	39.65
5	39.70	39.76	39.51	39.67
6	39.27	39.46	39.71	39.44
7	39.37	39.44	39.59	39.62
8	39.08	39.09	39.35	39.73
9	39.43	39.52	39.51	39.56
10	39.72	39.66	39.59	39.69
11	39.14	39.23	39.24	39.43
12	39.01	39.21	NS*	39.41

*NS = no sample

2.7.2.1 Nylon Twine

In the forested sites, the nylon twines lost less than 10% of their strength, indicating their total resistance to fungal attack and good resistance to sunlight. In the Hut, there was no measurable change in strength over the full year's exposure period, as would be expected. The twine in the Fort Sherman Open site experienced a 44% drop in strength after a year's exposure, which is again about what would be expected. Changes in elongation are of about the same magnitude as changes in strength.

TABLE 8. BREAKING STRENGTH OF NYLON TWINE (pounds)

Month	FSO	McK	Hut	SH
0	87.72	87.72	87.72	87.72
1	84.75	87.23	88.24	85.64
2	87.00	84.42	85.99	86.91
3	84.26	87.17	86.97	85.98
4	80.72	85.11	88.75	84.70
5	78.48	84.92	86.31	85.64
6	72.86	83.34	85.99	84.86
7	72.62	82.65	85.14	85.20
8	68.87	81.45	84.97	83.30
9	68.75	83.36	84.31	84.40
10	62.94	83.93	85.35	82.63
11	55.32	81.84	85.29	83.39
12	49.19	81.10	87.59	81.45

NYLON TWINE (concluded)

	Tenacity (grams force/denier)					Elongation at Break (percent)			
Month	FSO	McK	Hut	SH	Month	FSO	McK	Hut	SH
0	7.10	7.10	7.10	7.10	0	229.9	229.9	229.9	229.9
1	6.86	7.07	7.15	6.94	1	204.0	234.1	263.6	237.8
2	7.04	6.84	6.86	7.04	2	185.1	192.1	199.8	196.7
3	6.82	7.06	7.04	6.96	3	201.2	226.9	242.3	221.8
4	6.54	6.89	7.19	6.86	4	184.6	233.0	260.5	209.8
5	6.36	6.88	6.99	6.94	5	166.1	197.2	220.0	195.4
6	5.90	6.75	6.96	6.87	6	155.8	187.4	216.3	191.8
7	5.88	6.59	6.89	6.90	7	147.9	187.0	204.4	185.9
8	5.58	6.69	6.88	6.75	8	141.9	184.2	208.8	186.5
9	5.57	6.75	6.83	6.83	9	153.0	208.9	216.9	202.6
10	5.09	6.80	6.91	6.69	10	134.6	187.4	209.8	180.4
11	4.48	6.63	6.83	6.75	11	128.8	185.9	208.1	181.3
12	3.98	6.57	7.09	6.59	12	116.4	179.4	214.0	173.7

2.7.2.2 Natural (Unpigmented) Polypropylene Twine

Natural polypropylene has low resistance to actinic degradation and is thus an ideal material with which to measure the severity of a sunny environment apart from fungal and moisture effects, to which it is immune. At the Open site the twine experienced a near-total (98%) loss of strength at the end of the year, with relatively uniform deterioration at intermediate times. In the Hut, the strength loss was so small (4%) as to be within the limits of variability of the material. Strength losses of 35 to 40% were experienced at the forested sites, which is about as expected. Changes in elongation approximately parallel the changes in strength except for the last three months at the Open site, where the strength was so low that the friction between broken strands was great enough to result in an increase of elongation. Twine from two rolls was exposed. One roll which was below specification in both strength and denier was inadvertently used for all sites except McKenzie Forest. Although this shifted breaking load values downward about 31% and tenacity values downward about 24%, decreases in strength compared to control (unexposed) values seem to be about as expected.

TABLE 9. BREAKING STRENGTH, NATURAL POLYPROPYLENE TWINE

(pounds)

Month	FSO	McK	Hut	SH
0	198.9	288.9	198.9	198.9
1	195.8	277.3	183.1	200.7
2	148.2	275.4	193.0	209.8
3	123.1	269.1	193.9	196.6
4	122.0	270.5	189.9	188.4
5	114.9	256.5	188.6	203.5
6	76.9	249.9	193.4	170.6
7	54.4	227.1	192.2	180.5
8	41.3	191.9	199.1	166.4
9	25.7	180.5	198.6	150.3
10	15.3	171.3	198.3	137.4
11	13.3	170.3	196.2	136.9
12	4.3	167.2	189.4	129.4

NATURAL POLYPROPYLENE TWINE

Tenacity (grams force/denier)					Elongation (percent)				
Month	FSO	McK	Hut	SH	Month	FSO	McK	Hut	SH
0	2.865	3.753	2.865	2.865	0	31.96	41.62	31.96	31.96
1	2.783	3.492	2.673	2.930	1	33.60	38.93	30.28	34.91
2	2.164	3.743	2.817	3.063	2	19.04	36.95	32.89	33.04
3	1.797	3.657	2.831	2.870	3	15.82	35.81	31.36	30.07
4	1.782	3.677	2.773	2.750	4	23.70	43.91	37.34	38.65
5	1.678	3.589	2.754	2.971	5	19.75	36.54	30.47	32.50
6	1.122	3.650	2.824	2.491	6	17.67	35.73	29.84	38.42
7	.795	3.315	2.807	2.635	7	16.46	30.01	29.01	25.73
8	.603	2.985	2.907	2.429	8	19.36	29.97	30.86	25.93
9	.375	2.454	2.899	2.194	9	17.98	30.47	30.38	23.51
10	.224	2.328	2.949	2.006	10	27.93	22.40	28.22	20.03
11	.194	2.314	2.864	1.998	11	27.96	29.44	33.57	19.43
12	.63	2.272	2.764	1.889	12	25.13	21.90	29.23	24.00

2.7.2.3 Black polypropylene twine

Results of black polypropylene twine were similar to those of natural twine except that the black pigment in the twine serves as an ultraviolet absorber and its strength loss is about half of that of natural twine. An exception to this is that the deterioration in the Hut was substantially worse, about 15% strength loss over a year. (We are unable to explain this based on previous experience with polypropylene. It is possible that some ingredient in the twine renders it susceptible to fungal attack. The most severe environment was the Open site, with a strength loss of almost 52%, followed by the McKenzie Forest (19%), the Hut and the Skunk Hollow Forest site.

TABLE 10. BREAKING STRENGTH, BLACK POLYPROPYLENE TWINE (pounds)

Month	FSO	McK	Hut	SH
0	281.1	281.1	281.1	281.1
1	266.4	278.0	270.3	277.7
2	255.4	261.8	277.5	279.0
3	228.0	269.8	277.2	268.7
4	210.9	267.4	277.7	279.6
5	189.6	258.5	267.8	261.0
6	183.6	253.8	261.4	256.4
7	163.2	250.5	263.0	268.0
8	167.9	251.6	257.4	279.4
9	143.6	250.2	256.3	242.5
10	138.2	241.5	250.8	244.7
11	136.1	249.1	251.2	244.8
12	136.3	227.2	237.6	242.8

BLACK POLYPROPYLENE TWINE

Tenacity (grams force/denier)					Elongation (percent)				
Month	FSO	McK	Hut	SH	Month	FSO	McK	Hut	SH
0	3.548	3.548	3.548	3.548	0	57.59	57.59	57.59	57.59
1	3.362	3.508	3.411	3.453	1	61.47	57.41	61.55	56.76
2	3.224	3.303	3.502	3.521	2	44.88	52.60	52.73	56.80
3	2.877	3.405	3.499	3.391	3	43.15	54.77	55.58	54.71
4	2.662	3.375	3.505	3.529	4	40.45	55.70	59.84	60.85
5	2.393	3.268	3.380	3.294	5	41.85	50.67	52.00	51.01
6	2.317	3.203	3.300	3.237	6	43.91	57.44	50.04	51.80
7	2.059	3.162	3.319	3.382	7	39.07	48.81	48.15	49.51
8	2.199	3.175	3.248	3.526	8	35.00	49.64	50.39	52.35
9	1.813	3.157	3.235	3.061	9	33.96	54.07	49.85	52.00
10	1.744	3.048	3.166	3.038	10	40.85	43.9[illegible]	54.89	43.01
11	1.718	3.144	3.170	3.090	11	37.70	41.60	50.70	43.06
12	1.720	2.868	2.999	3.064	12	35.92	41.34	47.41	43.39

2.7.2.4 Cotton Twine

Cotton twine, a cellulosic material, is affected by ultraviolet light, moisture and fungal attack. Consequently it can be expected to show substantial deterioration in almost any humid tropic environment. In this case, in over a year's exposure it experienced a strength loss of 57% in the

Open site, 41% in the McKenzie Forest and the Hut, and 38% in Skunk Hollow. The increased severity in the Open site is probably attributable to actinic degradation. The difference in severity between Skunk Hollow and the Hut (100 yards apart) can be attributed to removal of nutrients by rain and inhibition of fungal growth by sunlight. From the results it can be seen that the humidity in the hut is sufficient for fungi to grow. Probably the only site significantly different from the others statistically is the Open site. Culture of fungi from the samples indicated that only one genus, *Penicillium*, was frequently found at all sites. It was also the only genus found more than once (5 times) on cotton samples at the Hut. Most of the others were observed predominantly at either the Open site (*Curvularia*, *Cladosporium* and *Phoma*) or at the Forested sites (*Trichoderma*, *Fusarium* and *Cephalosporium*). Other genera occured only once or twice out of eight fungal examinations and are considered "occasional".

TABLE 11. BREAKING STRENGTH, COTTON TWINE
(pounds)

Month	FSO	McK	Hut	SH
0	32.43	32.43	32.43	32.43
1	29.58	31.99	28.85	31.54
2	28.39	30.95	25.19	29.80
3	28.89	29.21	24.26	27.71
4	25.06	26.05	22.23	24.65
5	25.06	24.11	21.90	23.48
6	22.61	21.82	20.97	22.76
7	20.31	20.69	20.82	20.73
8	18.44	20.11	20.26	21.06
9	18.08	20.22	19.49	21.28
10	16.18	20.37	20.13	20.16
11	14.74	19.73	18.99	20.83
12	13.91	19.01	19.12	20.05

COTTON TWINE (cont)

	Tenacity (grams force/denier)					Elongation (percent)			
Month	FSO	McK	Hut	SH	Month	FSO	McK	Hut	SH
0	1.0241	1.0241	1.0241	1.0241	0	144.1	144.1	144.1	144.1
1	.9435	1.0212	.9208	1.0052	1	112.6	131.3	121.0	121.9
2	.9049	.9843	.8029	.9503	2	104.3	109.7	104.3	103.0
3	.9208	.9299	.7711	.8823	3	97.83	134.6	107.4	100.8
4	.7983	.8301	.7095	.7847	4	99.04	123.3	132.1	119.0
5	.7983	.7666	.6963	.7484	5	90.23	134.7	145.5	136.2
6	.7205	.6952	.6686	.7254	6	92.89	142.6	136.9	124.6
7	.6470	.6593	.6600	.6609	7	86.62	151.1	128.2	133.8
8	.5874	.6409	.6455	.6713	8	87.22	163.7	130.3	143.9
9	.5761	.6418	.6209	.6878	9	84.09	175.7	165.9	159.4
10	.5098	.6418	.6170	.6355	10	71.16	167.6	154.0	146.0
11	.4672	.6282	.6033	.6623	11	64.30	159.1	129.6	139.0
12	.4423	.6056	.6078	.6373	12	59.82	157.4	119.0	128.2

TABLE 12. COTTON TWINE FUNGUS

X = Fungus observed . = Fungus not observed

Open Site FUNGUS	25 JUN	25 JUL	25 OCT	28 NOV	27 DEC	25 JAN	26 MAR	25 APR
CURVULARIA	X	X	X	.	X	X	X	X
PENICILLIUM	X	.	X	.	X	.	.	.
FUSARIUM	X	.	.	X	.	.	.	.
CLADOSPORIUM	X	.	X	X	X	X	X	X
PHOMA	X	.	X	.	X	.	.	X
ASPERGILLUS	.	.	.	.	.	.	.	.
CEPHALOSPORIUM	.	.	.	.	.	.	.	.
TRICHODERMA	.	.	X	X	.	.	.	.
PESTALOTIA	.	.	.	.	.	.	X	.
GLIOCLADIUM	.	.	.	.	.	.	.	.
NIGROSPORA	.	.	.	X	.	.	.	.
STEMPHYLIUM	.	.	.	.	X	.	X	.
ALTERNARIA	.	.	.	.	.	.	X	.

COTTON TWINE FUNGUS (cont)

X = Fungus observed . = Fungus not observed

Hut FUNGUS	25 JUN	25 JUL	25 OCT	25 NOV	25 DEC	25 JAN	26 MAR	25 APR
CURVULARIA	X	.	.	.	.	.	.	.
PENICILLIUM	X	.	X	X	X	X	.	.
FUSARIUM	.	.	.	.	.	.	.	.
CLADOSPORIUM	.	.	.	.	X	.	.	.
PHOMA	X	.	.	.	.	.	.	.
ASPERGILLUS	X	.	.	.	.	.	.	.
CEPHALOSPORIUM	X	X	.	.	.	.	.	.
TRICHODERMA	.	X	.	.	.	.	.	.
PESTALOTIA	.	.	.	.	.	.	.	.
GLIOCLADIUM	.	.	.	.	.	.	.	.
NIGROSPORA	.	.	.	.	.	.	.	.
STEMPHYLIUM	.	.	.	.	.	.	.	.
ALTERNARIA	.	.	.	.	.	.	.	.

Skunk Hollow FUNGUS	25 JUN	25 JUL	25 OCT	28 NOV	27 DEC	25 JAN	26 MAR	25 APR
CURVULARIA	.	.	.	.	.	.	.	.
PENICILLIUM	.	.	X	X	X	.	.	.
FUSARIUM	.	.	.	.	X	X	X	X
CLADOSPORIUM	.	.	.	.	.	.	.	.
PHOMA	.	.	.	X	.	.	.	.
ASPERGILLUS	.	.	.	.	.	.	.	.
CEPHALOSPORIUM	.	X	.	X	X	.	.	.
TRICHODERMA	X	X	X	X	X	X	X	.
PESTALOTIA	.	.	.	.	.	.	X	.
GLIOCLADIUM	.	.	.	.	.	.	.	.
NIGROSPORA	.	.	.	.	.	.	.	.
STEMPHYLIUM	.	.	.	.	.	.	.	.
ALTERNARIA	.	.	.	.	.	.	.	.

COTTON TWINE FUNGUS (cont)

X = Fungus observed . = Fungus not observed

McKenzie FUNGUS	25 JUN	25 JUL	25 OCT	28 NOV	27 DEC	25 JAN	26 MAR	25 APR
CURVULARIA	.	.	.	.	.	.	.	.
PENICILLIUM	.	X	X	X	X	.	.	X
FUSARIUM	.	.	.	.	X	.	.	.
CLADOSPORIUM	.	X	.	.	X	.	X	.
PHOMA	X	.	.	.	.	.	.	X
ASPERGILLUS	.	.	.	.	.	X	.	.
CEPHALOSPORIUM	X	.	.	X	.	.	X	.
TRICHODERMA	.	.	X	X	X	X	X	X
PESTALOTIA	.	.	.	.	X	.	X	.
GLIOCLADIUM	.	X	.	.	.	.	.	.
NIGROSPORA	.	.	.	.	.	.	.	.
STEMPHYLIUM	.	.	.	.	.	.	.	.
ALTERNARIA	.	.	.	.	.	.	.	.

2.7.3 Polyvinyl Chloride (PVC) Insulated Tinned Copper Wire

Over the one-year exposure period there was no significant change in tensile strength of the insulated wire. In all cases the apparent resistance of the insulation of the entire sample (discounting obviously damaged areas) was approximately 6 megohms, indicating that there was no penetration of the insulation by fungal growth, cracks, etc. Although there was no apparent damage to the wire by microbial growth, a number of fungal genera were identified in active growth on the PVC insulation. Of these, Penicillium and Cladosporium were observed on samples from all sites, and were the only fungi observed more than once at the Hut. Aureobasidium was found at the Open site on 3 occasions and Pestalotia was found in both forested sites. Other fungi were found not more than twice at any site and are considered occasional.

TABLE 13. PVC INSULATED COPPER WIRE

Breaking Strength (pounds)					Elongation (per cent)				
Month	FSO	McK	Hut	SH	Month	FSO	McK	Hut	SH
0	34.86	34.86	34.86	34.86	0	48.56	48.56	48.56	48.56
1	34.80	34.69	35.51	34.75	1	50.47	47.54	56.22	46.06
2	34.90	34.84	34.93	34.66	2	54.24	51.02	56.59	50.54
3	34.89	34.99	34.86	35.10	3	41.42	47.09	44.70	45.59
4	34.88	34.97	34.96	34.88	4	43.78	44.69	49.13	47.51
5	34.83	35.03	34.97	34.96	5	51.84	54.09	52.01	49.66
6	35.09	35.43	35.08	35.68	6	42.28	40.63	42.16	39.17
7	35.30	35.55	35.23	35.75	7	40.40	37.52	43.42	38.62
8	35.25	35.67	35.41	35.68	8	41.33	37.06	42.19	37.99
9	35.31	35.30	35.55	35.23	9	40.79	40.97	41.49	43.61
10	35.23	35.22	35.29	35.22	10	40.96	43.87	43.79	46.51
11	35.37	35.26	35.43	35.16	11	38.74	48.11	43.93	45.40
12	35.36	35.40	35.39	35.28	12	40.83	43.63	46.49	48.30

TABLE 14. PVC INSULATED WIRE FUNGUS

X = Fungus Observed . = Fungus Not Observed

Open Site FUNGUS	25 JUN	25 JUL	25 OCT	28 NOV	27 DEC	25 JAN	23 FEB	26 MAR	25 APR
CURVULARIA	.	.	.	.	.	X	.	.	.
PENICILLIUM	.	.	X	.	.	.	.	X	X
FUSARIUM	.	.	.	.	.	.	.	.	.
CLADOSPORIUM	.	X	X	X	X	X	.	.	.
PHOMA	.	.	.	.	.	.	.	.	.
ASPERGILLUS	.	.	X	.	.	.	.	.	.
CEPHALOSPORIUN	.	.	.	.	.	.	.	.	.
TRICHODERMA	.	.	.	.	.	.	.	.	.
PESTALOTIA	.	.	.	.	.	.	.	.	.
GLIOCLADIUM	.	.	.	.	.	.	.	.	.
NIGROSPORA	.	.	.	.	.	.	.	.	.
STEMPHYLIUM	.	.	.	.	.	X	.	.	.
ALTERNARIA	.	.	.	.	.	.	.	.	.
MONILIA	.	.	.	X	X	.	.	.	.
AUREOBASIDIUM	.	X	.	X	.	.	X	.	.
PAECILOMYCES	.	.	.	.	.	.	.	.	.
RHINOCLADIELA	.	.	.	.	.	.	X	.	.

PVC INSULATED WIRE FUNGUS (cont)

X = Fungus Observed . = Fungus Not Observed

Hut FUNGUS	25 JUN	25 JUL	25 OCT	28 NOV	27 DEC	25 JAN	23 FEB	26 MAR	25 APR
CURVULARIA	.	.	.	.	.	.	.	.	.
PENICILLIUM	.	X	.	.	.	.	X	.	.
FUSARIUM	.	.	.	.	.	.	X	.	.
CLADOSPORIUM	.	.	X	X	X	.	.	.	.
PHOMA	.	.	.	.	.	.	.	.	.
ASPERGILLUS	.	.	.	.	.	.	.	.	.
CEPHALOSPORIUM	.	X	.	.	.	.	.	.	.
TRICHODERMA	.	.	.	.	.	.	.	.	.
PESTALOTIA	.	.	.	.	.	.	.	.	.
GLIOCLADIUM	.	.	.	.	.	.	.	.	.
NIGROSPORA	.	.	.	.	.	.	.	.	.
STEMPHYLIUM	.	.	.	.	.	.	.	.	.
ALTERNARIA	.	.	.	.	.	.	.	.	.
MONILIA	.	.	.	.	X	.	.	.	.
AUREOBASIDIUM	.	.	.	.	.	.	.	.	.
PAECILOMYCES	.	.	.	.	.	.	X	.	.
RHINOCLADIELA	.	.	.	.	.	.	.	.	.

Skunk Hollow FUNGUS	25 JUN	25 JUL	25 OCT	28 NOV	27 DEC	25 JAN	23 FEB	25 MAR	25 APR
CURVULARIA	.	.	X	.	.	.	.	.	.
PENICILLIUM	.	.	.	.	X	.	.	X	X
FUSARIUM	.	.	.	.	.	X	X	.	.
CLADOSPORIUM	.	.	X	X	X	.	X	.	.
PHOMA	.	.	.	.	.	.	X	.	.
ASPERGILLUS	.	.	.	.	.	.	.	.	.
CEPHALOSPORIUM	.	.	.	.	.	.	X	.	.
TRICHODERMA	.	.	.	.	.	.	.	.	.
PESTALOTIA	.	X	X	.	.	X	.	.	.
GLIOCLADIUM	.	X	.	.	.	.	.	.	.
NIGROSPORA	.	.	.	.	.	.	X	.	.
STEMPHYLIUM	.	.	X	.	.	.	.	.	.
ALTERNARIA	.	.	.	.	.	.	.	.	.
MONILIA	.	.	.	.	X	.	.	.	.
AUREOBASIDIUM	.	.	.	.	.	.	.	.	.
PAECILOMYCES	.	.	.	.	.	.	X	.	.
RHINOCLADIELA	.	.	.	.	.	.	.	.	.

PVC INSULATED WIRE FUNGUS (concluded)

McKenzie FUNGUS	25 JUN	25 JUL	25 OCT	28 NOV	27 DEC	25 JAN	23 FEB	26 MAR	25 APR
CURVULARIA	.	.	.	.	.	.	.	.	.
PENICILLIUM	.	.	X	X	.	.	.	.	.
FUSARIUM	.	.	.	.	.	.	X	.	.
CLADOSPORIUM	.	.	.	X	X	.	.	.	.
PHOMA	.	.	.	.	.	.	.	.	.
ASPERGILLUS	.	.	.	.	.	.	.	.	.
CEPHALOSPORIUM	.	X	.	.	.	.	X	.	.
TRICHODERMA	.	X	X	.	.	.	.	.	.
PESTALOTIA	.	.	.	.	.	X	X	.	.
GLIOCLADIUM	.	X	.	.	.	.	.	.	.
NIGROSPORA	.	.	.	.	.	.	.	.	.
STEMPHYLIUM	.	.	.	.	.	.	X	.	.
ALTERNARIA	.	.	.	.	.	.	.	.	.
MONILIA	.	.	.	X	.	.	.	.	.
STREPTOMYCES	.	.	X	.	.	.	X	.	.
PAECILOMYCES	.	.	.	.	.	.	.	.	.
RHINOCLADIELA	.	.	.	.	.	.	X	.	.

2.7.4 Wood Samples

Mechanical testing of wood samples yielded a relatively uniform decrease in strength at all sites. The decrease was most rapid and about equal at the two forested sites, where the reduction in strength was about 52% at the end of a year. At the Open site, the strength decreased about 31%, and at the Hut about 20%. Deflection at peak load decreased in a similar manner with the exception of the middle of the exposure period in the Hut. The reason for this anomalous increase in flexibility is not understood. Data obtained in determining whether or not samples were dry enough for mechanical testing were found to contain some interesting trends and are reported here to show the effect of the exposure environments and the dry season on the moisture absorption of the wood. Comparing values from the Hut with those from the forested sites shows the effect of rain in approximately equal humidity. Some of the samples in the dry season actually gained weight when brought into the air-conditioned laboratory. Values given are the sums of weight changes for the seven specimens on each panel. A wider range of fungi was observed on wood samples than on other materials. Cephalosporium, Trichoderma, Streptomyces and Paecilomyces were frequently observed at all sites. Curvularia, Phoma and Cladosporium were frequently found at the Open site, with Cladosporium also frequent at the Hut but not in the Forested sites. Penicillium and Fusarium were frequently found at the Forested sites and in the Hut. Gliocladium was found at Skunk Hollow and in the Hut but not at other sites. Likewise, Aureobasidium was found frequently at McKenzie Forest but not at Skunk Hollow. Comparison of these data with fungal data for other sites seems to indicate that the same fungi attack different materials at different sites, i.e., Aureobasidium was found on PVC wire insulation at the Open site but at McKenzie it seemed to prefer wood. *Cladosporium* was found on PVC wire insulation at all sites but was rare or absent on wood at forested sites.

TABLE 15. BREAKING LOAD IN BEAM BENDING, WOOD SAMPLES

Month	FSO	McK	Hut	SH
0	128.4	128.4	128.4	128.4
1	117.3	117.2	126.3	114.1
2	114.2	94.6	116.5	91.8
3	109.1	90.7	116.8	91.8
4	118.1	72.8	116.6	80.3
5	112.1	84.3	110.8	71.9
6	96.2	73.9	107.6	69.7
7	101.4	66.5	107.6	61.1
8	99.3	64.1	102.2	61.9
9	100.5	61.2	102.9	59.4
10	98.1	59.1	98.5	60.1
11	87.8	57.6	94.6	56.6
12	84.4	54.3	94.4	55.6

TABLE 16. Modulus of Rupture, Wood Samples
(thousands of pounds per square inch)

Month	FSO	McK	Hut	SH
0	15.83	15.83	15.83	15.83
1	14.46	15.66	16.11	14.32
2	14.63	15.84	14.63	12.06
3	14.32	11.54	14.76	11.40
4	14.32	9.60	13.87	10.67
5	14.23	10.33	13.12	8.60
6	13.30	8.31	14.15	9.25
7	12.80	8.89	13.63	8.06
8	12.15	7.67	13.04	8.51
9	12.42	8.03	13.13	7.85
10	12.26	7.77	12.43	7.87
11	12.50	7.70	12.66	7.43
12	10.90	7.60	12.98	7.56

TABLE 17. DEFLECTION AT BREAK, WOOD SAMPLES
(inches)

Month	FSO	McK	Hut	SH
0	.3689	.3689	.3689	.3689
1	.3856	.4245	.3503	.3664
2	.3269	.3114	.3866	.2642
3	.3222	.2376	.3812	.2305
4	.3773	.3143	.3252	.3446
5	.3532	.2892	.3329	.2726
6	.4328	.2658	.4656	.2996
7	.3313	.1758	.5124	.3003
8	.3[illegible]06	.2621	.3555	.3219
9	.2143	.2899	.2516	.1645
10	.3313	.2596	.3678	.2589
11	.3358	.2817	.4216	.2561
12	.2039	.1729	.3298	.1688

TABLE 18. WEIGHT LOSS UPON DRYING, WOOD SAMPLES
(for groups of seven samples)
(grams)

Month	FSO	McK	Hut	SH
1	.99	8.78	10.01	13.47
2	10.58	40.77	10.87	43.11
3	1.71	41.42	11.26	32.50
4	23.81	64.47	11.89	55.86
5	22.04	82.71	12.35	92.99
6	23.81	61.40	10.64	36.92
7	4.53	46.43	9.93	51.63
8	6.25	31.35	9.88	42.20
9	.05	3.53	4.77	4.37
10	-4.48	3.17	4.55	3.08
11	1.98	4.85	5.28	3.94
12	.61	4.41	4.35	6.84

TABLE 19. FUNGUS IN WOOD SAMPLES

X = Fungus observed . = Fungus not observed

Open Site FUNGUS	25 JUN	28 NOV	25 JAN	23 FEB	26 MAR	25 APR
CURVULARIA	X	X	X	X	X	X
PENICILLIUM	X	.	.	.	.	.
FUSARIUM	.	X		X	.	.
CLADOSPORIUM	X	X	X	X	X	X
PHOMA	X	X	X	X	X	X
ASPERGILLUS	.	X	X	.	.	.
CEPHALOSPORIUM	X	X	X	X	X	X
TRICHODERMA	X	X	X	X	X	X
PESTALOTIA	.	.	.	.	.	X
GLIOCLADIUM	.	.	.	.	.	.
NIGROSPORA	X	.	.	.	.	.
STEMPHYLIUM	.	X	.	.	.	.
ALTERNARIA	X	.	.	.	.	.
STREPTOMYCES	.	X	.	X	X	X
PAECILOMYCES	.	X	.	X	X	.
MONILIA	X	.	.	.	X	.
VERTICILLIUM	.	.	.	.	.	.
AUREOBASIDIUM	.	.	.	.	.	X
STYSANUS	.	.	.	.	.	.
PLENODOMUS	.	.	.	.	.	.
HELICOMYCES	.	.	.	.	.	.

FUNGUS IN WOOD SAMPLES (cont)

X = Fungus observed . = Fungus not observed

McKenzie FUNGUS	25 JUN	28 NOV	25 JAN	23 FEB	26 MAR	25 APR
CURVULARIA	X	.	.	.	.	.
PENICILLIUM	.	X	X	.	X	X
FUSARIUM	X	X	X	X	X	X
CLADOSPORIUM	.	.	.	.	.	.
PHOMA	X	.	.	.	.	.
ASPERGILLUS	X	.	.	.	.	.
CEPHALOSPORIUM	X	X	X	X	X	X
TRICHODERMA	X	X	X	X	X	X
PESTALOTIA	.	.	.	.	.	.
GLIOCLADIUM	.	.	.	.	.	.
NIGROSPORA	.	.	.	.	.	.
STEMPHYLIUM	.	.	.	.	.	.
ALTERNARIA	.	.	.	.	.	.
STREPTOMYCES	.	X	X	X	X	X
PAECILOMYCES	.	.	X	X	X	X
MONILIA	.	.	.	.	X	.
VERTICILLIUM	.	.	.	.	.	.
AUREOBASIDIUM	X	X	X	.	.	.
STYSANUS	X	.	.	.	.	.
PLENODOMUS	.	.	.	.	.	.
HELICOMYCES	X	.	.	.	.	X

FUNGUS IN WOOD SAMPLES (cont)

X = Fungus observed   . = Fungus not observed

Hut FUNGUS	25 JUN	28 NOV	25 JAN	23 FEB	26 MAR	25 APR
CURVULARIA	X	.	X	.	.	.
PENICILLIUM	X	X	X	X	X	X
FUSARIUM	X	X	X	X	X	X
CLADOSPORIUM	X	X	.	X	X	X
PHOMA	.	X	.	.	X	.
ASPERGILLUS	X	X	.	.	.	.
CEPHALOSPORIUM	X	X	X	X	X	X
TRICHODERMA	X	X	X	X	X	X
PESTALOTIA	.	.	.	.	.	.
GLIOCLADIUM	.	X	X	.	.	X
NIGROSPORA	.	.	.	.	.	.
STEMPHYLIUM	.	.	.	.	.	.
ALTERNARIA	.	.	.	.	.	.
STREPTOMYCES	.	X	X	X	X	X
PAECILOMYCES	.	X	X	X	X	.
MONILIA	X	.	.	.	X	.
VERTICILLIUM	X	.	.	.	.	.
AUREOBASIDIUM	.	.	.	.	X	.
STYSANUS	.	.	.	.	.	.
PLENODOMUS	.	.	.	.	.	.
HELICOMYCES	.	.	.	.	.	.

FUNGUS IN WOOD SAMPLES (concluded)

X = Fungus observed . = Fungus not observed

SH FUNGUS	25 JUN	26 NOV	25 JAN	23 FEB	26 MAR	25 APR
CURVULARIA	.	X	.	X	.	.
PENICILLIUM	.	X	.	X	.	.
FUSARIUM	X	X	.	X	X	X
CLADOSPORIUM	.	X	.	.	.	X
PHOMA	X	.	.	.	.	.
ASPERGILLUS	.	.	.	.	.	.
CEPHALOSPORIUM	X	X	X	X	X	X
TRICHODERMA	X	X	X	X	X	X
PESTALOTIA	X	X	.	.	.	X
GLIOCLADIUM	.	.	.	.	.	.
NIGROSPORA	.	.	.	.	.	.
STEMPHYLIUM	.	.	.	.	.	.
ALTERNARIA	.	.	.	.	.	.
STREPTOMYCES	.	.	.	X	X	X
PAECILOMYCES	.	X	X	X	X	X
MONILIA	.	.	.	.	X	.
VERTICILLIUM	.	.	.	.	.	.
AUREOBASIDIUM	.	.	.	.	.	.
STYSANUS	X	.	.	.	.	X
PLENODOMUS	X	.	.	.	.	.
HELICOMYCES	.	.	.	.	.	X

2.7.5 Printed Circuit Boards

After 3 month's exposure some differences in boards became apparent, with changes in properties which were independent of exposure sites. Some boards began to show substantially greater changes in both resistance and capacitance than others. Examination of the boards showed that they were also slightly different in appearance, with the boards which showed greater changes having a lighter colored layer in the center of the fiberglass/epoxy composite laminate. These were found to correspond to lot number 3431 A2. Both lots were represented at all sites except the Open site which had only lot 2921 L1. All tabulated data show means for each lot, preceded by means for control boards of that lot (month "0"), and followed by "final" values which were obtained after scrubbing to remove organic debris and excess corrosion products, and drying for two weeks. These "final" values give an indication of the reversibility of the changes which were observed. In most instances, values were partly but not completely reversible. All boards (except control boards, which remained constant in all values throughout the test) exhibited increases in apparent capacitance and dissipation and decreases in resistance. Certain values were not measurable with the equipment used and others were not measured at the beginning and end of the test for other reasons (equipment failures, etc). Dashed lines in the following tables indicate unmeasurable dissipation. Lot 3431 A2 showed greater changes than did 2921 L1 in all cases. Dissipation values for lot 3431 A2 ranged from apparently unmeasuraby low to 2.37 (237%) at 120 Hz in the Hut, while in the forested sites the maximum values were 0.603 to 0.724. By comparison, boards from lot 2921 L1 never exhibited a measurable value for dissipation at 120 Hz and highest values at 1 kHz were in the range of 0.220 to 0.385 or about half the values of lot 3431 A2. Capacitances of all boards were initially 35 to 38 picofarads (pF). The maximum increase for boards from lot 2921 L1 ranged from 84 to 100%, while boards from lot 3431 A2 increased as much as 145 to 225% (some more than tripled in value). The greatest reversible and nonreversible changes in capacitance of 2921 L1 boards was at the Open site followed by the Hut and the two forested sites. A possible explanation is that both actinic degradation and fungal growth permanently damage the surface of the board causing it to retain more moisture, while in the forested sites the rain washes off the nutrients and is then dried by the sun. The sunlight is probably not bright enough to result in much actinic degradation in those sites. In the Hut, the nutrients and spores remain in place and degrade the surface. Results were similar for the 3431 A2 boards although much more pronounced, with a 145% increase in capacitance at 120 Hz at both forested sites and a 225% increase in the Hut. These increases were somewhat reversible with final values of capacitance increased by about 40% in the forested sites and about 60% in the Hut. Dissipation values were also much higher, with maximum values of 2.37 in the Hut and .57 to .61 in the forested sites. Dissipation values were much less reversible than capacitances, especially for lot 3431 A2. This indicates that these boards would be particularly unsuitable for high impedance circuits in a humid environment.

TABLE 20. ELECTRICAL PROPERTIES OF PRINTED CIRCUIT BOARDS

Open Site 2921 L1 Month	120 Hz C,pF	120 Hz D	120 Hz RES	1 kHz C,pF	1 kHz D	1 kHz RES	10 kHz C,pF	10 kHz D	10 kHz RES
0	37.3	----	>20	36.3	.018	>20	35.6	.012	>20
1	46.3	----	>20	40.4	----	>20	37.9	----	*
2	50.8	----	>20	42.6	.113	>20	39.1	.048	*
3	53.7	----	>20	43.8	.132	>20	39.5	.057	*
4	55.5	----	>20	44.6	.144	>20	39.9	.061	8.1
5	57.3	----	>20	45.9	.147	>20	40.7	.069	5.6
6	53.7	----	>20	44.0	.131	>20	39.6	.059	6.9
7	57.2	----	>20	45.4	.149	>20	40.1	.070	5.7
8	59.0	----	>20	47.2	.154	>20	41.3	.079	4.9
9	67.1	----	>20	50.5	.380	6.2	48.3	.101	5.9
10	75.2	----	>20	53.8	.259	11.4	43.9	.122	2.9
11	74.5	----	>20	55.0	.445	6.9	*	*	*
12	66.6	----	>20	51.9	.205	13.9	*	*	*
FINAL	58.8	----	>20	46.1	.142	>20	*	*	*

Mckenzie 2921 L1 Month	120 Hz C,pF	120 Hz D	120 Hz RES	1 kHz C,pF	1 kHz D	1 kHz RES	10 kHz C,pF	10 kHz D	10 kHz RES
0	37.3	----	>20	36.3	.018	>20	35.6	.012	>20
1	71.3	----	>20	53.5	----	>20	45.5	----	*
2	66.3	----	>20	51.0	.179	>20	44.5	.088	*
3	61.5	----	>20	48.6	.163	>20	42.6	.088	*
4	64.8	----	>20	50.2	.172	18.1	43.6	.085	4.3
5	66.8	----	>20	51.4	.179	17.3	44.1	.091	4.0
6	68.3	----	>20	51.7	.186	16.3	44.3	.093	3.9
7	68.5	----	>20	51.5	.193	15.7	43.9	.095	3.9
8	66.3	----	>20	50.9	.182	17.2	43.7	.089	4.1
9	65.1	----	>20	51.6	.253	12.6	43.0	.087	3.5
10	63.8	----	>20	48.1	.191	17.2	41.5	.084	4.6
11	63.5	----	>20	52.0	.259	12.0	*	*	*
12	54.3	----	>20	44.1	.131	>20	*	*	*
FINAL	48.8	----	>20	41.4	.155	>20	*	*	*

TABLE 20. ELECTRICAL PROPERTIES OF PRINTED CIRCUIT BOARDS (cont)

McKenzie 3431 AC	120 Hz			1 kHz			10 kHz		
Month	C,pF	D	RES	C,pF	D	RES	C,pF	D	RES
0	37.5	----	>20	36.3	.024	>20	35.4	.014	>20
1	85.5	----	>20	57.0	----	*	45.1	----	0
2	83.0	.523	>20	55.3	.266	*	44.9	.118	*
3	77.5	.510	>20	54.0	.260	*	44.3	.111	*
4	80.0	.459	>20	56.4	.246	13.5	45.6	.119	3.6
5	84.0	.452	>20	58.2	.250	10.8	46.6	.127	2.7
6	84.5	.450	>20	58.3	.252	10.7	46.6	.128	2.7
7	90.0	.473	>20	60.5	.271	9.5	47.4	.140	2.4
8	82.5	.437	>20	57.8	.242	11.3	46.5	.124	2.8
9	92.0	.569	>20	60.9	.318	8.1	46.7	.125	2.2
10	84.0	.522	>20	55.1	.275	10.2	44.4	.125	2.9
11	92.0	.724	>20	63.1	.364	6.8	*	*	*
12	65.0	----	>20	47.6	.185	17.7	*	*	*
FINAL	53.0	----	>20	42.6	.114	>20	*	*	*

Hut 2921 L1	120 Hz			1 kHz			10 kHz		
Month	C,pF	D	RES	C,pF	D	RES	C,pF	D	RES
0	37.3	----	>20	36.3	.018	>20	35.6	.012	>20
1	78.0	----	>20	52.5	----	>20	42.9	----	*
2	60.5	----	>20	46.2	.179	>20	40.8	.071	*
3	68.2	----	>20	49.2	.267	>20	41.9	.096	*
4	65.5	----	>20	48.2	.211	15.5	41.6	.085	4.6
5	69.0	----	>20	49.7	.230	13.6	42.3	.095	3.9
6	69.0	----	>20	49.6	.227	14.0	42.5	.093	4.1
7	74.0	----	>20	51.7	.253	12.1	43.3	.105	3.6
8	72.5	----	>20	51.2	.246	12.5	43.4	.103	3.6
9	73.0	----	>20	50.9	.263	11.8	42.6	.104	3.6
10	75.0	----	>20	51.2	.288	10.7	42.5	.110	3.5
11	76.5	----	>20	51.8	.309	9.9	*	*	*
12	59.5	----	>20	45.7	.181	>20	*	*	*
FINAL	51.0	----	>20	41.9	.117	>20	*	*	*

TABLE 20. ELECTRICAL PROPERTIES OF PRINTED CIRCUIT BOARDS (cont)

Hut 3431 A2 Month	120 Hz C,pF	120 Hz D	120 Hz RES	1 kHz C,pF	1 kHz D	1 kHz RES	10 kHz C,pF	10 kHz D	10 kHz RES
0	37.5	----	>20	36.3	.024	>20	35.4	.014	>20
1	114.0	----	>20	60.7	----	*	43.9	----	*
2	91.3	.762	>20	53.8	.369	*	42.2	.137	*
3	113.8	2.37	>20	55.6	.812	*	44.2	.228	*
4	101.8	.818	15.9	58.2	.420	6.5	43.4	.161	2.3
5	107.5	.786	15.6	60.1	.427	5.9	44.3	.172	2.1
6	105.8	.822	15.0	60.0	.429	6.1	44.5	.171	2.1
7	112.8	.836	13.8	62.4	.451	5.6	45.4	.184	1.9
8	109.8	.875	13.6	61.9	.445	5.7	45.6	.178	1.9
9	115.8	.953	11.9	62.6	.486	5.1	45.3	.188	1.9
10	122.0	.949	10.3	64.8	.530	4.5	45.7	.207	1.7
11	119.5	1.11	9.4	65.7	.560	4.3	*	*	*
12	79.5	.894	>20	38.0	.342	9.1	*	*	*
FINAL	60.0	----	>20	44.2	.213	17.3	*	*	*

Skunk Hollow 2921 L1 Month	120 Hz C,pF	120 Hz D	120 Hz RES	1 kHz C,pF	1 kHz D	1 kHz RES	10 kHz C,pF	10 kHz D	10 kHz RES
0	37.3	----	>20	36.3	.018	>20	35.6	.012	>20
1	78.0	----	>20	55.4	----	>20	46.1	----	*
2	65.0	----	>20	50.7	.165	>20	44.3	.084	*
3	63.0	----	>20	48.9	.177	>20	42.6	.080	*
4	64.0	----	>20	49.4	.172	18.6	43.1	.082	4.6
5	66.5	----	>20	50.9	.181	16.9	43.8	.089	4.1
6	67.0	----	>20	50.5	.185	16.8	43.6	.089	4.2
7	73.5	----	>20	53.7	.218	13.4	44.9	.105	3.4
8	66.0	----	>20	50.6	.180	17.2	43.6	.088	4.2
9	67.3	----	>20	51.9	.202	12.5	43.0	.092	3.5
10	68.5	----	>20	49.6	.220	14.5	41.9	.095	4.1
11	69.0	----	>20	48.9	.203	16.6	*	*	*
12	53.5	----	>20	43.6	.119	>20	*	*	*
FINAL	47.0	----	>20	41.1	.074	>20	*	*	*

TABLE 20. ELECTRICAL PROPERTIES OF PRINTED CIRCUIT BOARDS (cont)

Skunk Hollow 3431 A2	120 Hz			1 kHz			10 kHz		
Month	C,pF	D	RES	C,pF	D	RES	C,pF	D	RES
0	37.5	----	>20	36.3	.024	>20	35.4	.014	>20
1	99.0	----	>20	59.6	----	*	46.0	----	*
2	79.5	.499	>20	54.5	.255	*	44.4	.115	*
3	76.8	----	>20	52.8	.248	*	43.4	.110	*
4	80.0	.469	>20	55.0	.252	11.2	44.5	.120	2.9
5	84.5	.475	>20	57.2	.263	10.4	45.5	.130	2.7
6	83.0	.468	>20	56.8	.259	10.4	45.3	.127	2.8
7	91.3	.503	>20	60.5	.289	8.9	46.9	.145	2.3
8	83.3	.450	>20	57.3	.254	10.8	45.6	.128	2.7
9	88.3	.544	>20	58.3	.299	7.4	45.7	.138	2.2
10	92.0	.603	>20	57.5	.331	8.2	44.2	.147	2.5
11	86.8	.460	>20	56.0	.301	9.5	*	*	*
12	61.8	----	>20	46.4	.181	18.8	*	*	*
FINAL	50.3	----	>20	40.9	.102	>20	*	*	*

Control 2921 L1	120 Hz			1 kHz			10 kHz		
Month	C,pF	D	RES	C,pF	D	RES	C, pF	D	RES
0	37.3	----	>20	36.3	.018	>20	35.6	.012	>20
1	38.0	----	>20	36.4	----	>20	35.7	----	>20
2	37.2	----	>20	36.2	.015	>20	35.6	.012	>20
3	36.5	----	>20	36.5	.017	>20	35.5	.011	>20
4	36.5	----	>20	36.2	.016	>20	35.6	.012	>20
5	37.0	----	>20	35.9	.016	>20	35.4	.012	>20
6	37.3	----	>20	36.4	.017	>20	35.8	.012	>20
7	36.8	----	>20	36.3	.016	>20	35.6	.012	>20
8	37.0	----	>20	36.4	.016	>20	35.7	.012	>20
9	37.5	----	>20	36.3	.019	>20	35.6	.014	>20
10	37.5	----	>20	36.4	.021	>20	35.7	.013	>20
11	38.3	----	>20	36.9	.024	>20	*	*	*
12	37.8	----	>20	36.5	.017	>20	*	*	*
MEAN	37.3	----	>20	36.3	.018	>20	35.6	.012	>20

TABLE 20. ELECTRICAL PROPERTIES OF PRINTED CIRCUIT BOARDS (concluded)

Control 3431 A2 Month	120 Hz C,pF	120 Hz D	120 Hz RES	1 kHz C,pF	1 kHz D	1 kHz RES	10 kHz C,pF	10 kHz D	10 kHz RES
1	38.0	----	>20	36.4	----	>20	35.6	----	>20
2	37.5	----	>20	36.2	.021	>20	35.4	.014	>20
3	36.5	----	>20	36.1	.021	>20	35.5	.012	>20
4	37.5	----	>20	36.1	.021	>20	35.4	.014	>20
5	37.0	----	>20	35.9	.025	>20	35.2	.014	>20
6	38.0	----	>20	36.3	.024	>20	35.5	.014	>20
7	38.0	----	>20	36.2	.026	>20	35.4	.014	>20
8	37.5	----	>20	36.3	.023	>20	35.5	.014	>20
9	38.0	----	>20	36.2	.025	>20	35.4	.015	>20
10	37.5	----	>20	36.4	.028	>20	35.4	.013	>20
11	37.5	----	>20	36.8	.024	>20	*	*	*
12	37.5	----	>20	36.5	.023	>20	*	*	*
MEAN	37.5	----	>20	36.3	.024	>20	35.4	.014	>20

* During the final three months, data were taken with the HP 4261 LCR meter which only measures at 120 Hz and 1 kHz.

C, pF= Capacitance in picofarads, RES= Resistance in megohms
D= dielectric dissipation factor (unitless)

2.7.6 Glass Plates

Changes in optical or photographic density of the glass plates were much smaller than would be expected after visual examination. Although the Hurter and Driffield (H & D) density units used to measure visual obscuration in this study are logarithmic, in the range of values experienced here, they are approximately linear. The lowest value, 0.04, is equivalent to 91% transmittance, and the highest value, 0.08, is equivalent to 83% transmittance. Although fungal growth was evident on most of the plates except in the Open site, it was predominantly in the form of sterile mycelia and were not identifiable. This was particularly the case in the Forested sites because much of the organic debris and other nutrients were washed off by rain. At the Open site there was less debris, about as much rain and strong sunlight which also inhibited fungal growth. The final four months of exposure were during dry season, and the lack of rain and its washing effect are evident in the data. No measurable permanent effects were noted on the plates; that is, chemical cleaning restored all of them to their original clarity. Some of the debris and growth on the plates was identifiable by microscopic examination. In addition to sterile fungal mycelia, the following were found on plates in the forested sites: moss, spores of Fusarium and other fungi, lichens, dust, leaf particles, insect parts, pollen, flowers and seeds from trees and other jungle plants and droppings from birds and other animals. In the Hut the deposits were similar in nature, with the exception of moss, leaf particles, and flowers. Although there were no birds in the Hut, during part of the exposure period the Hut was occupied by a few bats which also left evidence of their presence on the plates. At the Open site evidence of fungal growth was also found, although much less than the other sites. Other debris found on the plates at the Open site included spores, pollen, sand, dust, and bird and insect droppings. In general, except for dust, the plates from the Open site appeared much cleaner than those from other sites. The lack of permanent effects on the glass (etching) was somewhat surprising due to the many reports of etching of glass in optical equipment stored in the tropics. It may be that the etching observed was in some way catalyzed or accelerated by lens coatings, mounting cements or water entrapped within the affected instrument. Nonetheless, there is no room for doubt that fungi can and do grow on glass and other relatively inert materials, using nutrients supplied by most of the remainder of the ecosystem. (These nutrients may be one essential ingredient lacking from most fungal chamber tests.) Photomicrographs of selected growths and particulates can be made available on request to USATTC (ATTN: STETC-MTD-P).

TABLE 21. PHOTOGRAPHIC DENSITY OF EXPOSED GLASS PLATES, H & D UNITS

	FSO		McK		Hut		SH	
Month	AR	CL	AR	CL	AR	CL	AR	CL
0	.05	.05	.05	.05	.05	.05	.05	.05
1	.05	.05	.05	.05	.05	.05	.04	.04
2	.06	.05	.06	.05	.06	.05	.05	.04
3	.06	.05	.06	.05	.06	.06	.05	.04
4	.05	.05	.06	.05	.06	.05	.05	.05
5	.05	.05	.06	.05	.07	.05	.07	.05
6	.05	.05	.06	.05	.06	.05	.07	.05
7	.06	.05	.06	.05	.07	.05	.06	.05
8	.05	.05	.07	.05	.06	.05	.06	.05
9	.06	.05	.06	.05	.06	.05	.07	.05
10	.05	.05	.07	.05	.06	.05	.07	.05
11	.05	.05	.07	.05	.07	.05	.08	.05
12	.06	.05	.08	.05	.07	.05	.08	.05

AR = As Retrieved, CL = Cleaned. Densities in H&D Units

2.8 RECOMMENDATIONS FOR CHAMBER TESTING OF MATERIALS

2.8.1 The Indicated Chamber Tests Recommended for the Materials Listed

Bare and Galvanized wire: Humidity
PVC insulated wire: Solar radiation, Fungus
Cotton twine: Solar radiation, Humidity, Fungus
Nylon and Polypropylene twines: Solar radiation
Circuit boards: Solar radiation, Humidity
Wood samples: Solar radiation, Humidity, Fungus
Glass plates: None (A long term fungus test could be run if desired, but would require a full complement of nutrients in the inoculant.)

Where more than one type of test is specified, tests should probably be run consecutively, first in the order shown above, and if unsatisfactory results are obtained, the order may be changed. The philosophy of the above order is that actinic degradation will probably "soften" the materials up by rendering the surface more susceptible to permeation by moisture, which will in turn enhance the susceptibility to fungal growth. Although possibly more time-consuming, the most logical approach seems to be to expose and test small quantities of those materials which will be destructively tested. This will prevent accumulation of samples which have been partly exposed in an environment later determined to be of insufficient severity. A tentative sequence follows the discussion of the environmental chamber exposures.

2.8.2 Mechanical and Electrical Testing, General

Although many parameters were measured, some of them provided much more volume, redundancy and confusion than worthwhile information. For that reason many of those parameters, although measured accurately, are not presented in this report. Also, values presented in this report are mean values for groups of samples retrieved at one time from each site, and generally represent 5, 6, or 7 tests. A listing of all of those values would triple the volume of this report without yielding a significant increase in usefulness. If individual values are required by the chamber test facility, they will be provided upon request to the author. To simplify testing, parameters measured should be limited to those parameters presented in this report, unless they are required for the calculation of other values. Testing should be conducted as promptly as possible after retrieval of samples (allowing for drying where necessary), and as far as equipment will allow, in accordance with methods described in section 2.6 of this report. As noted above, the following parameters should be measured:

Bare and Galvanized wire: Breaking strength only
PVC Insulated wire: Breaking strength, elongation and insulation resistance
Twines: Breaking strength, tenacity and elongation
Wood: Breaking load, modulus of rupture and deflection at break
Circuit Boards: Capacitance, resistance and dielectric dissipation at 120Hz, 1kHz and 10kHz

2.8.3 Solar Radiation

Since actinic degradation is the principal effect sought in this test (as opposed to thermal cycling) the method specified in MIL-STD-810D method 505.2, procedure 2 is the most desirable starting point. The specified illuminance is approximately 100 langleys per hour, so that a 24 hour cycle (20 hours with lights on) gives approximately 2000 langleys, or roughly the equivalent of 4 days at the Open site. For initial investigations the optimum timing would be 7 or 10 day test cycles followed by mechanical testing to measure the effects. When the mechanical tests show a decrease of 10 to 20% for materials to be exposed to other environments, or 40 to 50% for materials which will only be subjected to this environment, exposure should be considered sufficient. For circuit boards, the effect of sunlight apart from humidity on dielectric properties is unknown. Therefore, if boards appear faded or the buses are beginning to peel without appreciable change in measurable properties, the exposure should be considered sufficient.

2.8.4 Humidity

For a starting point, the method given in MIL-STD-810D method 507.2, procedure III (Aggravated) is preferable. The method specifies cycles of 10 days, which will probably be satisfactory. Following chamber exposure, samples to be subjected to mechanical or electronic testing must be dried to equilibrium with the laboratory environment prior to testing. Experience has shown overnight drying to be sufficient for cordage and circuit boards, but wood samples need to be weighed periodically until their weight is constant prior to mechanical testing. It is possible that no major changes will be seen in mechanical properties of cordage and wood samples. This does not mean that the humidity testing is in vain, because the effect of humidity over the short term may be relatively small. Nonetheless, it is expected to enhance the susceptibility of the materials to fungal growth. Samples should be removed, dried and tested (and in the case of circuit boards, returned to the chamber) after each 10 day cycle. For cordage, humidity effects will probably reach the point of diminishing returns by the end of the third cycle. A quick check of the condition of bare and galvanized wires can be made visually on the basis of the amount of visible corrosion. It is possible for bare wire and very likely for galvanized wire that sufficient corrosion to significantly affect the tensile strength will not occur in a reasonable time. If this is the case, testing of wire will have to be abandoned for the second phase of this project. An assessment of wood sample effects can probably be made by noting the gain in weight compared to the original weight prior to exposure in the humidity chamber. Values will probably be in the range of 10 to 95 grams. It will probably not be worthwhile to do any mechanical testing until a gain of at least 10 grams (for a panel of 7 samples) is observed. Likewise, a gain of 85 grams is probably all that can be expected. It may take a week or more for wood samples to dry to equilibrium weight after chamber exposure. Do not conduct mechanical tests until they are fully dry, as this will grossly affect their strength and flexibility. For circuit boards, the optimum time to remove them is probably at the conclusion of the high temperature portion of the cycle so that they can dry more quickly. They can be laid out on a table or in a dish drainer in an air-conditioned room and will be dry enough to test in 16 hours. Following testing, the boards should be returned to the chamber at the same point in the cycle at which they were removed for continued exposure. (It is recognized that this probably yields somewhat different results than having sufficient boards to remove some and not replace them after testing, but also has the advantage of being able to trace the effects on the same boards over an extended period, as well as requiring fewer boards.)

2.8.5 Fungus

a. Of the fungal genera regularly observed in natural environment testing, the only one specified for chamber testing in MIL-STD-810D was Penicillium. Aspergillus was rare or absent (depending on the material), as was Chaetomium. The following genera were regularly observed on samples at all sites:

Penicillium	Trichoderma
Cladosporium	Streptomyces (on wood samples only)
Cephalosporium	Paecilomyces (on wood samples only)

b. In addition to the above, Curvularia and Phoma were regularly observed at the Open site, and Fusarium was regularly observed at Skunk Hollow and in the Hut (but not at McKenzie). For this reason it seems appropriate to run some comparison tests to determine if there is a difference in the destructive effects of the two groups of fungi. If substantial differences are noted and the fungi found in the natural environment are more destructive, they should be considered as possible alternatives to those specified by MIL-STD-810D, particularly for a more severe or accelerated test. Cotton twine is probably the quickest and easiest material upon which to do this comparison test and probably need not be subjected to other environments first. It is recommended that the following fungi be used in this comparison against the MIL-STD-810D fungi:

Cladosporium	Phoma
Trichoderma	Fusarium
Paecilomyces	

c. Penicillium is not recommended for this comparison because of its inhibitory action toward other fungi. The chamber method should be as specified in MIL-STD-810D method 508.3 at least as a starting point, using 28 day cycles to a maximum of 84 days. As in the Humidity test, samples must be dry prior to mechanical testing. If the fungal growth is too slow or mechanical properties do not decrease to a significant degree, consideration should be given to using the above fungi and increasing the temperature of both the warmer and cooler portions of the cycle by 5 degrees C (9 degrees F). This will probably increase the activity of the fungi without endangering their viability.

2.8.6 Exposure/Testing Sequences

2.8.6.1 Bare and Galvanized Steel Wire

a. Baseline Mechanical Testing.

b. Humidity Chamber Exposure (cycle until corrosion is observed, abandon if none observed after 4 cycles).

c. Mechanical Testing.

d. If strength loss is between 5 and 40%, expose sufficient samples in chamber to allow retrieval and testing after each cycle until a strength loss of approximately 50% is reached. If in doubt, expose more samples.

e. Retrieve samples from chamber and test following each cycle, continuing until a 50% loss in strength or 6 cycles is reached. (6 cycles is considered the maximum feasible time for this test.)

2.8.6.2 PVC Insulated Wire

a. Baseline Testing (electrical and mechanical).

b. Solar Radiation (1 cycle).

c. Electrical Testing, rinse well, dry.

d. If no change in resistance, reexpose for another cycle (maximum of 6 cycles).

e. If a change in resistance is noted, expose new samples to solar radiation chamber for one cycle less than that at which the change was noted. If no change was noted, expose to 4 cycles.

f. Expose samples in fungus chamber using fungi determined to be most aggressive to cotton twine in the comparison test in paragraph 2.8.5 above. (Alternatively the fungi found most often on PVC insulated wire may be used. These were Penicillium, Cladosporium, Aureobasidium and Pestalotia.) Expose for 28 day cycles until fungal growth is evident, to a maximum of 3 cycles or 84 days.

g. At the end of each cycle, retrieve a sample and test electrically.

h. If resistance has changed, rinse, dry and test mechanically.

i. Continue retrieving samples and testing until 3 cycles have been completed.

j. If resistance has not changed at the completion of 3 fungus exposure cycles, test mechanically and terminate exposure.

2.8.6.3 Cotton twine

a. Baseline mechanical testing of all packages to be used.

b. Comparison fungus testing as outlined in paragraph 2.8.5 above. Sufficient samples for three retrievals should be exposed. Both groups should be conditioned in the chamber and removed for inoculation only, then incubated together. At the end of each of three 28 day cycles, samples of both groups should be retrieved, dried and mechanically tested.

c. Concurrently with the above exposure and testing, conduct solar Radiation exposure and testing. Expose sufficient samples for six retrievals in the chamber.

d. At the end of each 10 day cycle, retrieve samples and mechanically test.

e. Expose enough additional samples for 8 retrievals in the solar radiation chamber for the number of cycles required to produce a 10-20% drop in strength. At the completion of this exposure, mechanically test one group of samples to confirm the strength reduction.

f. Place the remaining samples in the humidity chamber and expose, retrieve, dry and mechanically test samples for three 10 day cycles.

g. Subject the remaining samples to fungus testing as soon as possible (so they don't dry out) using the fungi determined by the comparison test to be more aggressive (and including Penicillium in any case). Retrieve, dry and mechanically test samples after each of three 28 day cycles.

h. If at the end of the Fungus test cycles the strength is more than 50% of baseline value, repeat the testing starting at item 5. above, but use Penicillium, Cladosporium, Trichoderma, Paecilomyces, Phoma and Fusarium for the Fungus test and increase fungus chamber temperatures for the entire cycle by 5 degrees C (9 degrees F).

2.8.6.4 Nylon and Polypropylene Twines

a. Baseline mechanical testing of all packages to be used.

b. Solar Radiation Testing. Expose enough of each twine for six retrievals in the solar radiation chamber.

c. Retrieve and mechanically test samples at the end of each of six 10 day cycles.

2.8.6.5 Printed Circuit Boards

a. Baseline electronic testing of all boards.

b. Retain one-third of the boards in air-conditioned storage as control samples to be tested alongside exposed samples.

c. Solar Radiation Testing: Expose one-third of the boards in the solar radiation chamber. Remove them and test electronically at the end of each 10 day cycle to a maximum of six cycles. Return them to the chamber as soon as possible after testing. (If possible, test boards during the 4 hours of darkness in the cycle so they miss as little of the "daytime" as possible.)

d. During solar radiation testing, if any of the boards begin to appear faded, or if the buses begin to peel from the substrate, the Solar Radiation portion of the test should be terminated.

e. Following the solar radiation portion of the test, all boards except the controls should be subjected to humidity testing. Ideally, boards should be removed for testing at the conclusion of the high-temperature portion of the humidity cycle for drying and testing, for most rapid drying. They can be placed in a dish drainer or other clean rack so that both sides are exposed to air circulation, in an air-conditioned room. They should be sufficiently dry to test in 16 hours and after testing, they should be replaced in the humidity chamber at the same point in the cycle at which they were removed, for continued exposure. This should be done at the end of each of six 10 day cycles.

f. Following the testing after humidity chamber exposure the boards should be washed with a weak detergent solution and a brush, dried and placed in a desiccator for two weeks. Following this, they should be given a final test to determine the reversibility of changes observed.

2.8.6.6 Wood Samples

a. Baseline testing. A selection of samples of varying thicknesses should be mechanically tested for baseline data.

b. Samples should be measured for thickness and weighed prior to assembly on panels. Following assembly, the panels should be weighed also to facilitate determination of water absorption and drying.

c. Sufficient panels should be assembled for 23 retrievals.

d. Thirteen panels should be exposed to solar radiation. At the end of each of six 10 day cycles samples should be retrieved and mechanically tested.

e. The remaining seven panels, plus seven additional unexposed panels, should be subjected to humidity testing. One panel of each group should be retrieved, dried and mechanically tested at the end of each of four 10 day humidity cycles.

f. The remaining panels, plus three unexposed panels, should be exposed in the fungus chamber. One panel of each of the three groups should be retrieved, dried and mechanically tested at the end of each of three 28 day cycles. Fungi used for inoculation should be those determined most aggressive in the cotton twine comparison test in paragraph 2.8.5 above. If the average modulus of rupture does not decrease by at least 20% during the combined fungus and humidity cycles, eight additional panels should be prepared. Five of these should be exposed to the full six cycles of solar radiation followed by mechanical testing of one panel to confirm previous results. The remaining four should be exposed to four 10 day humidity cycles followed by drying and testing of one panel to confirm previous results. The remaining three plus three panels of unexposed samples should be exposed to the modified fungus test using *Penicillium*, *Cladosporium*, *Trichoderma*, *Paecilomyces*, *Phoma* and *Fusarium* for inoculation and increase fungus chamber temperatures for the entire cycle by 5 degrees C (9 degrees F).

2.8.7 Sample materials to be furnished by USATTC include the following:

Bare steel wire
Galvanized steel wire
PVC insulated wire
Cotton twine
Nylon twine
Natural polypropylene twine
Black polypropylene twine

Wood samples and mounting boards
Glass plates

No circuit boards are currently available (other than the six used for controls, which are from 2 lots). They can be ordered from the manufacturer listed in section 2.1. When ordering boards it should be clearly specified that all boards are to be from the same lot.

SECTION 3. DISTRIBUTION LIST

Natural Exposure vs Chamber Simulation
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