N83 10521 D16-44

# Environmental Isolation Task

C.D. Coulbert, Chairman

A review of the scope of PV module encapsulation technology made available to the industry through the various FSA-supported contracts and studies under the Flat-Plate Collector Research, Engineering Sciences, and Module Performance and Failure Analysis Areas shows it to be very broad (see p. 322). This technology has enabled the PV industry to respond with module designs and hardware with the potential of meeting module cost, performance and life goals. However, a review of these specific technology areas continues to stress the need for continuing module durability research to define module life-limiting degradation mechanisms so they can be quantified, predicted, and corrected. In these early days of PV module development, the great value of durability testing and failure analysis has been to identify design weaknesses; this has been used by industry to develop guidelines by which manufacturers could design and fabricate higher-quality hardware incorporating fault-tolerant design features.

Current FSA research activities are focused on identifying, modeling, and quantifying those long-term degradation mechanisms that would limit the ultimate service life of a PV module. At the same time, research is continuing on encapsulation materials and processes that have the greatest potential of increasing module life and efficiency and effectively reducing module cost.

The following visual presentations summarize significant progress in these areas during the reporting period.

Inasmuch as polymeric encapsulant material properties that may change with long-term field exposure do not necessarily result in a corresponding module damage or failure mode, it has become necessary to organize the failure-analysis process into a more specific set of long-term degradation steps so that material property change can be differentiated from module damage and module failure (see pp. 324-325). These categories allow separation, testing and modeling of the various degradation mechanisms with a clear distinction of which effects interact and which are sequential.

The polymeric aging computer model being developed by the University of Toronto will eventually predict what physical property changes may occur as a function of exposure time and environment. Additional analysis and experimental work are still required to relate polymer property change to module performance loss.

Encouraging developments in increasing module performance and life are indicated by the data on module surface treatments for soiling resistance, by improved bonding techniques and primers, by anti-corrosion treatments and by improved polymer stabilizers.

A new photoacoustic technique for very early detection of polymer surface reactions due to aging is being developed and evaluated at JPL. Such techniques are needed if the 20-year potential of modules is to be assessed and validated based on correlating field tests with accelerated tests over a limited number of months of durability testing.

# ENCAPSULATION TECHNOLOGY AVAILABLE

JET PROPULSION LABORATORY

C.D. Coulbert

| PV MODULE DESIGN | DESIGN ANALYSIS | FAILURE ANALYSIS |
|---|---|---|
| • PERFORMANCE REQ.<br>• LOADS & HAZARDS<br>• AVAILABLE MATERIALS & PROCESSES<br>• DESIGN ANALYSES & GUIDELINES<br>• LIFE LIMITING MODES | • PERFORMANCE EST.<br>• PHYSICAL DURABILITY ANALYSIS<br>• PREDICTED PROPERTY CHANGES<br>• NOCT/HOT SPOT TEMP.<br>• DESIGN OPTIONS<br>• QUALITY CONTROL REQUIREMENTS<br>• DAMAGE VS. PROPERTY CHANGE<br>• MODULE WEAK LINK | • PERFORMANCE LOSS<br>• WHAT FAILED<br>• WHY FAILED<br>• PROPERTY CHANGE<br>• PROGNOSIS<br>• CORRECTIVE ACTION<br>• PREDICTABILITY<br>• ACCEPTABILITY |

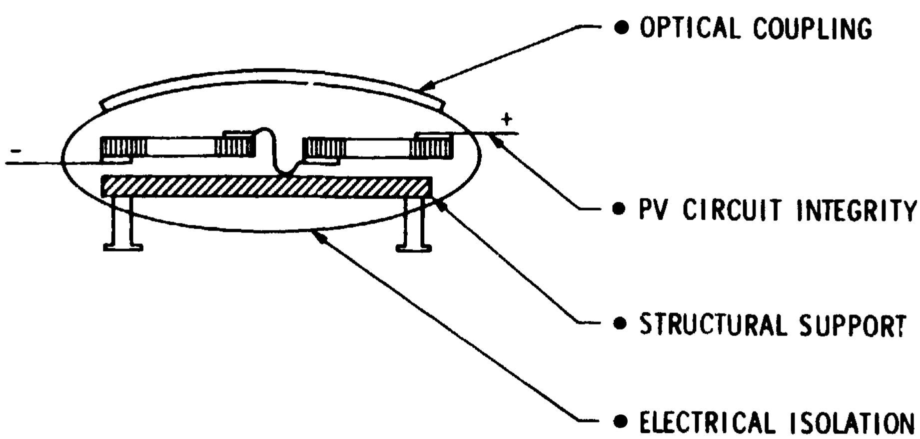
## Encapsulation Materials and Processes

- o SURFACE TREATMENTS BASED ON FLUOROCARBONS FOR LOW SOILING MODULE COVERS HAVE REDUCED OPTICAL LOSSES FROM 10% UNTREATED TO 3% OVER A TEN MONTH TEST PERIOD. (TESTING CONTINUES) (SPRINGBORN)
- o NEW CURING AGENTS IDENTIFIED FOR EVA AND EMA TO REDUCE CURING TEMPERATURES AND TIMES. CURING TIMES MAY BE REDUCED FROM 15 MINUTES TO LESS THAN 5 MINUTES(SPRINGBORN)
- o CORROSION RESISTANT COATINGS IDENTIFIED FOR MILD STEEL SUBSTRATE PANELS. TEST SPECIMENS HAVE SURVIVED SALT SPRAY FOR 3000 HOURS WITHOUT DETERIORATION. (SPRINGBORN)
- o EXPERIMENTAL BONDING PRIMER SYSTEMS DEVELOPED AND BEING EVALUATED FOR BONDING EVA AND EMA TO POLYESTER FILMS AND ALSO PRIMERS FOR CORROSION INHIBITION OF MILD STEEL. (DOW CORNING)
- o ION-PLATING AS METHOD FOR NON-FIRED METALLIZATION (TI/AL-Cu) ON SOLAR CELL n-SURFACE DEMONSTRATED. POTENTIAL FEASIBILITY FOR p-SURFACE SHOWN EXPERIMENTALLY. (ITW)
- o TWO NEW POLYMERIZABLE UV STABILIZERS FORMULATED FOR MODULE ACRYLIC COVER FILMS SHOW EXCELLENT UV CUT-OFF SPECTRAL CHARACTERISTICS. (UNIV. OF MASSACHUSETTS).

## Encapsulant Material Stability

- EVA FORMULATION A9918 HAS SURVIVED > 30,000 HOURS (3.5 YR) OF RS/4 SUNLAMP 55°C EXPOSURE WITHOUT DAMAGE. (SPRINGBORN)
- ADVANCED ENCAPSULANT MATERIALS (EVA, PU, HARDBOARD, CONCRETE, ETC.) IN MINI-MODULE TESTS HAVE ALMOST TWO YEARS OF FIELD EXPOSURE AND PASSED JPL QUAL TESTS. (JPL)
- SUBSTRATE MODULES WITH EVA AND WOOD HARDBOARD SUBSTRATES PASS HAIL IMPACT TESTS. (JPL)
- NEW DIAGNOSTIC TECHNIQUE (LASER PHOTOACOUSTICS) MEASURES POLYMER SURFACE PHOTO OXIDATION AND CORRELATES 60-DAY FIELD EXPOSURE WITH 10-HOUR LAB TESTS. (JPL)
- FULL-SIZE MODULE TEST FACILITY FOR ACCELERATED UV THERMAL TESTING COMPLETED AND INITIAL TESTS IN PROCESS. (JPL)
- MATERIAL PROPERTY (MOLECULAR WEIGHT, STRENGTH, TOUGHNESS AND STABILITY) PREDICTION BY COMPUTER MODEL OF POLYMER MOLECULAR STRUCTURE DEVELOPED AND DEMONSTRATED. (ROCKWELL SCIENCE CENTER)
- MODULE RESPONSES TO ENVIRONMENT AS A FUNCTION ENCAPSULANT PROPERTIES AND THICKNESSES PREDICTABLE BY COMPUTER MODELING. REDUCED VARIABLE MASTER CURVES DEVELOPED FOR CELL STRESS PREDICTION FOR WIND AND TEMPERATURE. (SPECTROLAB AND JPL)
- COMPUTER MODEL OF EVA PHOTODEGRADATION YIELDS DEGRADATION PRODUCTS VS TIME. LONG INCUBATION PERIOD INDICATED (5 - 10 YEARS). (UNIV. OF TORONTO)
- REPORT ON EXPERIMENTAL PHOTOTHERMAL CHARACTERIZATION OF CANDIDATE POTTANTS AND COVER FILM MATERIALS EXPOSED TO UV AND AIR UP TO 105°C COMPLETED AND IN PUBLICATION. (JPL).

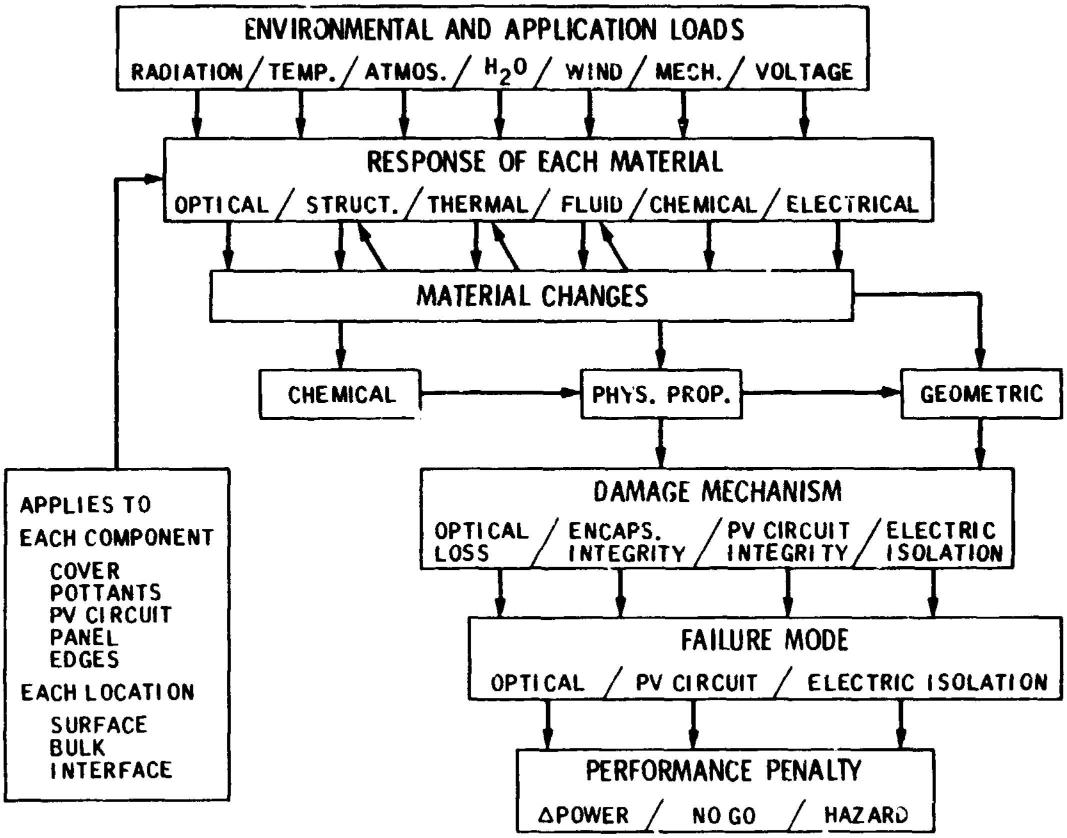
## Encapsulation Requirements




WHEN ONE OF THESE IS VIOLATED
YOU HAVE <u>DAMAGE</u> AND POTENTIAL <u>FAILURE</u>

ORIGINAL PAGE IS
OF POOR QUALITY

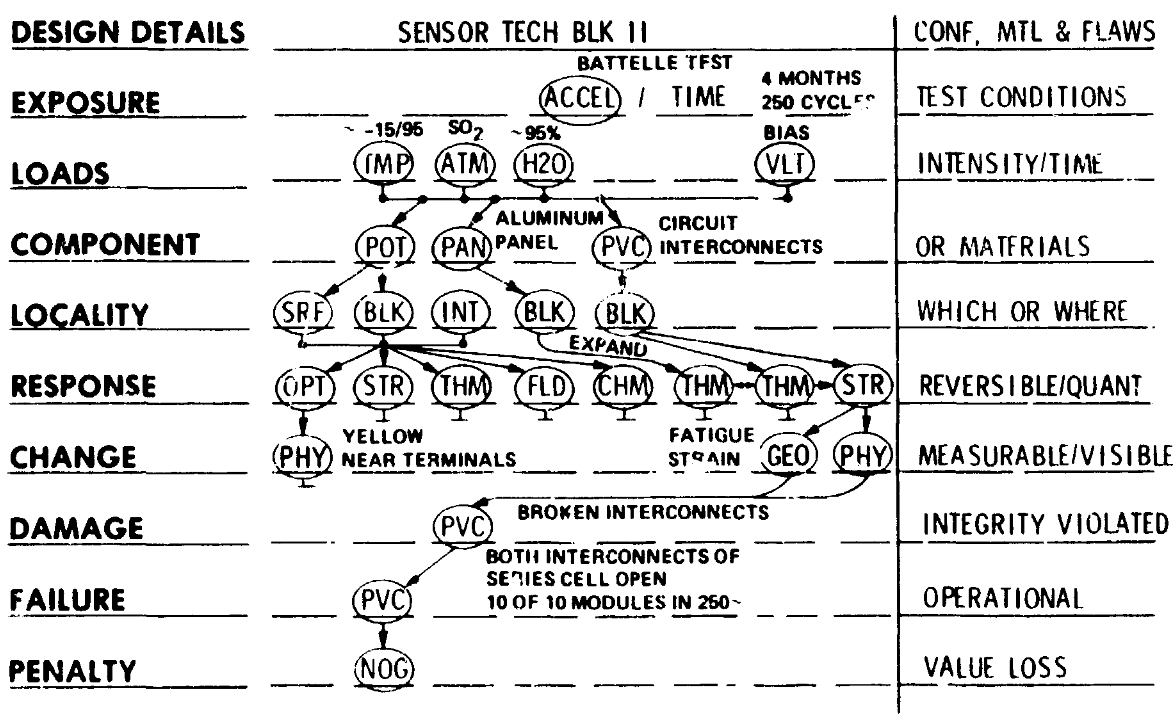
## PV Module Failure Analysis Sequence



## Durability Analysis Categories

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **DESIGN DETAILS** | | | | | | | | | MT'L & CONFIG. |
| **EXPOSURE** | QUAL | FIELD | ACCEL / TIME | | | | | | TEST CONDITIONS |
| **LOADS** | RAD | TMP | ATM | H2O | WND | MEC | VLT | | INTENSITY/TIME |
| **COMPONENT** | COV | POT | PAN | EDG | PVC | | | | OR MATERIALS |
| **LOCALITY** | SRF | BLK | INT | | | | | | WHICH OR WHERE |
| **RESPONSE** | OPT | STR | THM | FLD | CHM | ELC | | | QUANTITATIVE |
| **CHANGE** | CHM | PHY | GEO | | | | | | MEASURABLE/VISIBLE |
| **DAMAGE** | OPT | ENC | PVC | ISO | | | | | INTEGRITY |
| **FAILURE** | OPT | PVC | ISO | | | | | | OPERATIONAL |
| **PENALTY** | PWR | NOG | HZD | | | | | | VALUE LOSS |

## Example



ORIGINAL PAGE IS OF POOR QUALITY



# MATERIAL RESEARCH AND EVALUATION

## SPRINGBORN LABORATORIES, INC.

## Candidate Pottant Materials

SHEET LAMINATION GRADES:

- EMA
- EVA

CASTING SYRUPS:

- POLYBUTYL ACRYLATE
- ALIPHATIC POLYURETHANE

PHASES:

- INDUSTRIAL EVALUATION GRADE
- TECHNOLOGY READINESS STAGE

CURRENT WORK:

- ADVANCED CURE SYSTEMS
- THERMAL AGING EVALUATION
- ADVANCED STABILIZATION

# Pottants

INVESTIGATION OF PEROXIDE CURING AGENTS:

- CURE POLYMER TO HIGH GEL CONTENTS
- CURE IN THE RANGE OF 120°C TO 160°C WITH NO PREMATURE "SCORCH" AT 110°C
  MUST BE SOLUBLE IN THE RESIN AND NON-VOLATILE TO PREVENT LOSS
- MUST NOT SENSITIZE THE AGING OF THE RESIN (NON-AROMATIC)
  MUST BE COMPATIBLE WITH THE STABILIZERS AND OTHER INGREDIENTS
- MUST NOT PRODUCE CHEMICALLY ANTAGONISTIC BYPRODUCTS OR RESULT IN BUBBLING

GENERAL MECHANISM:

1. $RO\text{-}OR \xrightarrow{\Delta} 2\ RO\cdot$
2. $P\text{-}H + RO\cdot \longrightarrow P\cdot + ROH$
3. $2P\cdot \longrightarrow P - P$ (CROSSLINK)

- TERTIARY HYDROGENS ON THE POLYMER BACKBONE MOST READILY ABSTRACTED.
- CURING MUST BE CONDUCTED IN THE ABSENCE OF OXYGEN TO BE EFFECTIVE AND TO PREVENT OXIDATION OF THE RESIN.

## Pottant Compounds

ADVANCED CURE SYSTEMS IN EVA

| CURE TEMP. | TIME REQUIRED FOR 70% GEL CONTENT | | | | |
|---|---|---|---|---|---|
| | 120 | 130 | 140 | 150 | 160 |
| LUPERSOL 101 | N/A | N/A | 45 | 15 | 6 |
| LUPERSOL 99 | 30 | 20 | 12 | 8 | 2 |
| LUPERSOL 331-80B | 15 | 10 | 5 | 2 | 2 |
| LUPERSOL TBEC | 30 | 10 | 4 | 2 | 1 |

. ALL PEROXIDES COMPOUNDED INTO STANDARD FORMULA, A9918.

. NO CURE OCCURS AT 110°C WITH ANY PEROXIDE: SHOULD SURVIVE EXTRUSION OK.

ADVANCED CURE SYSTEMS IN EMA

| | TIME REQUIRED FOR 50% GEL CONTENT | | |
|---|---|---|---|
| | 130°C | 140°C | 150°C |
| LUPERSOL 101 | N/A | 60 | 30 |
| LUPERSOL 99 | 30 | 15 | 5 |
| LUPERSOL 331-80B | 15 | 10 | 5 |
| LUPERSOL TBEC | 25 | 5 | $<2$ |

. ALL PEROXIDES TESTED IN STANDARD FORMULA NO. 13439.

. NO CURE AT 110°C IN ANY FORMULATION: SHOULD SURVIVE EXTRUDER OK.

NEW CURING AGENTS FOR EVA AND EMA

| | % ACTIVE | ONE HOUR HALF-LIFE TEMPERATURE | FLASH POINT (VOLATILITY) |
|---|---|---|---|
| LUPERSOL 101 | 100% | 138°C | 43°C |
| LUPERSOL 331-80B | 75% | 111°C | 40°C |
| LUPERSOL 99 | 75% | 118°C | 77°C |
| LUPERSOL TBEC A. | 100% | 120°C | 101°C |

- LUPERSOL TBEC CURING AGENT OF CHOICE:
- HIGHEST CURING EFFICIENCY
- 100% ACTIVE, NO DILUENT
- LOWEST VAPOR PRESSURE

TECHNOLOGY VOIDS:

- PLANT EXTRUSION RUNS
- SHELF LIFE DETERMINATION
- COMPATABILITY WITH ADHESION SYSTEM

A. LUPERSOL TBEC IS 0,0-T-BUTYL-0-(2-ETHYL HEXYL) PEROXY CARBONATE

ETHYLENE VINYL ACETATE, A9918
(COMMERCIAL FORMULATION)

CAVEAT:

- CURING AGENT (PEROXIDE) IS SLIGHTLY VOLATILE

  KEEP THE EVA IN ROLL FORM WHERE LOSS IS INHIBITED

- DO NOT USE CUT SHEET WHICH HAS BEEN OPENLY EXPOSED FOR OVER ONE DAY

ROLLS APPEAR TO HAVE INDEFINITE SHELF LIFE.

NEED TO DETERMINE PEROXIDE LOSSES VERSUS TIME AND STORAGE CONDITIONS

# Butyl Acrylate Casting Syrup

FORMULA: BA 13870

- INDUSTRIAL SAMPLES AVAILABLE - (LABORATORY PROCESS)

CURE TIME GUIDE

| | 25°C | 35°C | 50°C | 60°C | 70°C |
|---|---|---|---|---|---|
| TIME TO ONSET OF CURE (MINUTES) | STABLE(A) | STABLE(A) | 60 | 25 | 6.5 |

- PILOT PLANT QUANTITIES
- INITIATOR AND DATA SHEET SUPPLIED WITH EACH REQUEST
- PRIMER: TENTATIVE RECOMMENDATION SPRINGBORN 14588 (DOW CORNING Z-6020 WITH TETRAETHYL SILICATE) ALSO PROVIDED WITH REQUEST

A. STABLE AT LEAST ONE WEEK, REFRIGERATION SUGGESTED.

## Aliphatic Urethane Encapsulant

FORMULA: Z-2591

- AVAILABLE - DEVELOPMENT ASSOCIATES, INC.
  NORTH KINGSTOWN, R.I.
- COST: APPX. $3.00 PER POUND
  (MIXED SYSTEM)
- CONTACT: MR. BUD NANNIG
- PRIMER:
  - TENTATIVE RECOMMENDATION
    DOW CORNING Z-6020
    (10% SOLUTION IN METHANOL)
  - BAKE PRIMERS ALSO
    AVAILABLE - DEVELOPMENT
    ASSOCIATES, INC.

ORIGINAL PAGE IS
OF POOR QUALITY

## RS/4 Exposures

POTTANT COMPOUNDS:

| POTTANT | HOURS | % PROPERTY RETAINED TENSILE | ELONGATION |
|---|---|---|---|
| URETHANE Z-2591 | 4,000 | 82% | 91% |
| EMA 23439 | 7,600 | 120% | 119% |
| EMA 11877 | 15,000 | 130% | 117% |
| EMA 2205 (UNCOMPOUNDED) | 15,000 | 5% | 5% |
| | | REMOVED | |
| BUTYL ACRYLATE 13870 | 7,[illegible] | 60% | 88% |
| EVA W/UV-2098 | JUST STARTED | | |
| EVA W/5-VINYL TINUVIN REACTED IN | 15,000 | 77% | 78% |

REFERENCE:

| | | |
|---|---|---|
| POLYETHYLENE UNSTABILIZED | 500 | 10% |
| POLYPROPYLENE UNSTABILIZED | 500 | 0% |

OUTER COVER AND BACK COVER FILMS:

| OUTER COVER FILM | HOURS | % PROPERTY RETAINED TENSILE | ELONGATION |
|---|---|---|---|
| ACRYLAR X-22417 | 12,000 | 54% | 100% |
| TEDLAR 100 BG 30 UT | 14,000 | 94% | 98.5% |
| TEDLAR 4662 | 10,800 | 140% | 38% |
| TEDLAR 05VT (W/VINYL TINUVIN) | 10,800 | 67% | 1% |
| FLUOREX-A | 10,800 | 70% | 30% |
| BACK COVER FILMS | | | |
| TEDLAR 200 BS 30 WH | 10,800 | 98% | 93% |
| SCOTCHPAR 20CPW | 6,600 | 95% | 74% |
| KORAD 63000 | 6,600 | 94% | 71% |

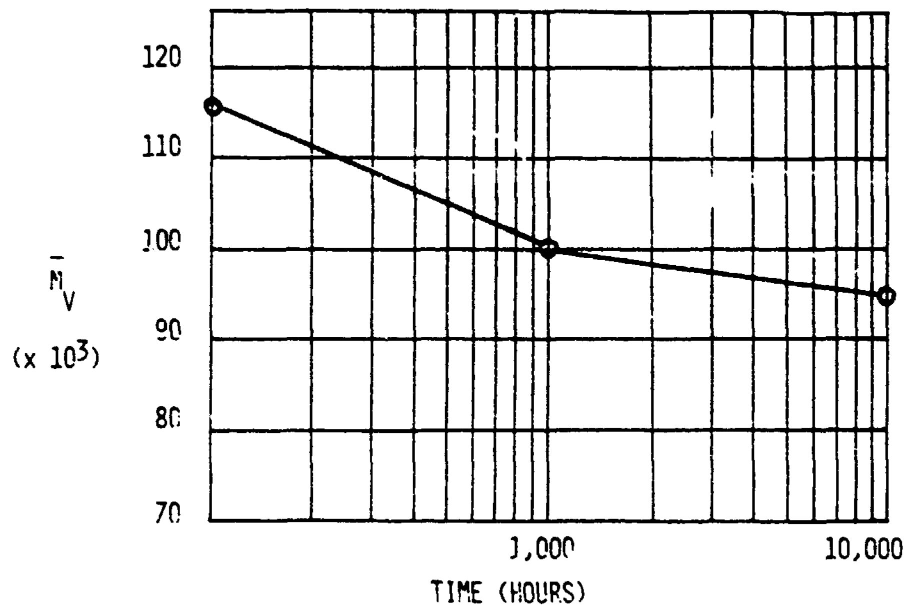
- TEDLARS (BOTH CLEAR AND PIGMENTED) APPEAR TO BE MOST STABLE.

"ACRYLAR" BIAXIALLY ORIENTED

ACRYLIC FILM

( 3M X 22417 )

DECREASE IN VISCOSITY AVERAGE MOLECULAR WEIGHT WITH EXPOSURE TIME.




MOLECULAR WEIGHT DECREASES FROM 116,000 TO 94,800 IN 10,000 HOURS TIME.

## ENVIRONMENTAL ISOLATION TASK



EVA POTTANT
(NO COVER FILM)

- CLEAR STABILIZED EVA EXPOSED 30,000 HOURS, LITTLE CHANGE.

| | TOTAL INTEGRATED TRANSMISSION (%) | ULTIMATE* ELONGATION (%) | TENSILE* STRENGTH (PSI) |
|---|---|---|---|
| CONTROL | 91 | 510 | 1890 |
| EXPOSED 30,000 HRS. | 90 | 480 | 1450 |
| % CONTROL | 99% | 94% | 77%[A.] |

UNSTABILIZED ELVAX 250 (EVA) BECOMES SOFT, TACKY, - LOSES PHYSICAL PROPERTIES IN LESS THAN 1,000 HOURS.

*ASTM D-638

A. FIRST SIGN OF CHANGE NOTICES THROUGHOUT EXPOSURE PERIOD

## Substrate Materials

CURRENT CANDIDATES

| MATERIAL | ¢/FT² | $/M² |
|---|---|---|
| COLD ROLLED MILD STEEL, 28 GAUGE | 15.5 | 1.67 |
| SUPER DORLUX HARDBOARD (MASONITE CORP.) | 14.0 | 1.51 |
| DURON TEMPERED HARDBOARD (US GYPSUM COMPANY) | 14.5 | 1.56 |

- SUBSTRATE ALLOCATION APPROX. 70¢/FT²
- COST INCREMENT WILL APPEAR FOR PROTECTIVE TREATMENT

PROTECTIVE COATINGS OR TREATMENTS REQUIRED FOR LONG OPERATING LIFE IN OUTDOOR ENVIRONMENT

POSSIBILITIES:

- ENCAPSULATE ENTIRE SUBSTRATE WITH WEATHERABLE POTTANT
- LAMINATION WITH OCCULSIVE FOIL:[A.]
  E.G.: "HOT-FOIL" TREATMENT
  (ALUMINUM FOIL WITH HOT MELT ADHESIVE)
- LAMINATE WITH ORGANIC FILMS
- COATING WITH WEATHERABLE ENAMEL[B.] OR PAINT
- COMBINATIONS OF THESE
- CHEMICAL MODIFICATION (WOOD)

A. TECHNIQUE BEING DEVELOPED BY U.S. GYPSUM AND OTHERS.

B. RECOMMENDATIONS FROM:

DOW CORNING CORPORATION

DEXTER - MIDLAND CORPORATION
STEEL STRUCTURES PAINTING
COUNCIL (SSPC)

TESTING

TEST "MODULES" PREPARED WITH COATED STEEL PANEL, BUTYL SEALANT AND GASKET

# Corrosion Experiments

MILD STEEL SUBSTRATES
SALT SPRAY EXPOSURE
(ASTM B-117)

| COATING | ADHESIVES | HOURS | CONDITIONS |
|---|---|---|---|
| ACRYLAR | ACRYLIC | 2,000 | R |
| SCOTCHPAR | ACRYLIC | 2,000 | R |
| ALUM. FOIL | ACRYLIC | 1,500 | R |
| KORAD (WHITE) | ACRYLIC | 2,000 | R |
| EVA | SILANE | 1,500 | R |
| CLEAR KORAD | ACRYLIC | 2,000 | R |
| ACMITITE | ACRYLIC | 2,500 | R |
| WHITE TEDLAR | ACRYLIC | 2,000 | R |
| 302 STAINLESS | ACRYLIC | 2,500 | R |
| EVA/SCOTCHPAR | SILANE | 4,500 | I |
| EVA/STAINLESS | SILANE | 2,500 | R |
| EVA/TEDLAR | SILANE | 2,500 | R |
| SCOTCHCLAD | NONE | 2,000 | R |
| EVA | CHROMATE/SILANE | 4,000 | II |
| VINYLIDENE/FLUORIDE | EPOXY | 3,500 | III |
| SILICONE/POLYESTER | EPOXY | 3,100 | II |
| ACRYLIC AUTO TOPCOAT | EPOXY | 3,100 | III |

I NO OBSERVABLE CHANGE
II SOME SIGNS OF DETERIORATION (CORROSION, DELAMINATION)
III NOTICEABLE DETERIORATION
R SPECIMEN FAILED, REMOVED

ORIGINAL PAGE IS OF POOR QUALITY

MILD STEEL SUBSTRATES

OUTDOOR EXPOSURE, ENFIELD, CT.

| COATING | ADHESIVES | HOURS | CONDITIONS |
|---|---|---|---|
| ACRYLAR | ACRYLIC | 4,500 | II |
| SCOTCHPAR | ACRYLIC | 4,500 | II |
| ALUM. FOIL | ACRYLIC | 4,500 | I |
| KORAD (WHITE) | ACRYLIC | 4,500 | II |
| EVA | SILANE | 4,500 | II |
| CLEAR KORAD | ACRYLIC | 1,500 | R |
| ACMITITE | ACRYLIC | 4,500 | I |
| WHITE TEDLAR | ACRYLIC | 4,500 | I |
| 302 STAINLESS | ACRYLIC | 4,500 | II |
| EVA/SCOTCHPAR | SILANE | 4,500 | I |
| EVA/STAINLESS | SILANE | 4,500 | II |
| EVA/TEDLAR | SILANE | 4,500 | II |
| SCOTCHCLAD | NONE | 4,500 | II |
| EVA | CHROMATE/SILANE | 4,000 | II |
| VINYLIDENE FLUORIDE | EPOXY | 3,400 | II |
| SILICONE/POLYESTER | EPOXY | 3,100 | II |
| ACRYLIC AUTO TOPCOAT | EPOXY | 3,100 | II |

I NO OBSERVABLE CHANGE
II SOME SIGNS OF DETERIORATION (CORROSION, DELAMINATION)
III NOTICEABLE DETERIORATION
R SPECIMEN FAILED, REMOVED

ORIGINAL PAGE IS
OF POOR QUALITY

# Hardboard Protection Experiments

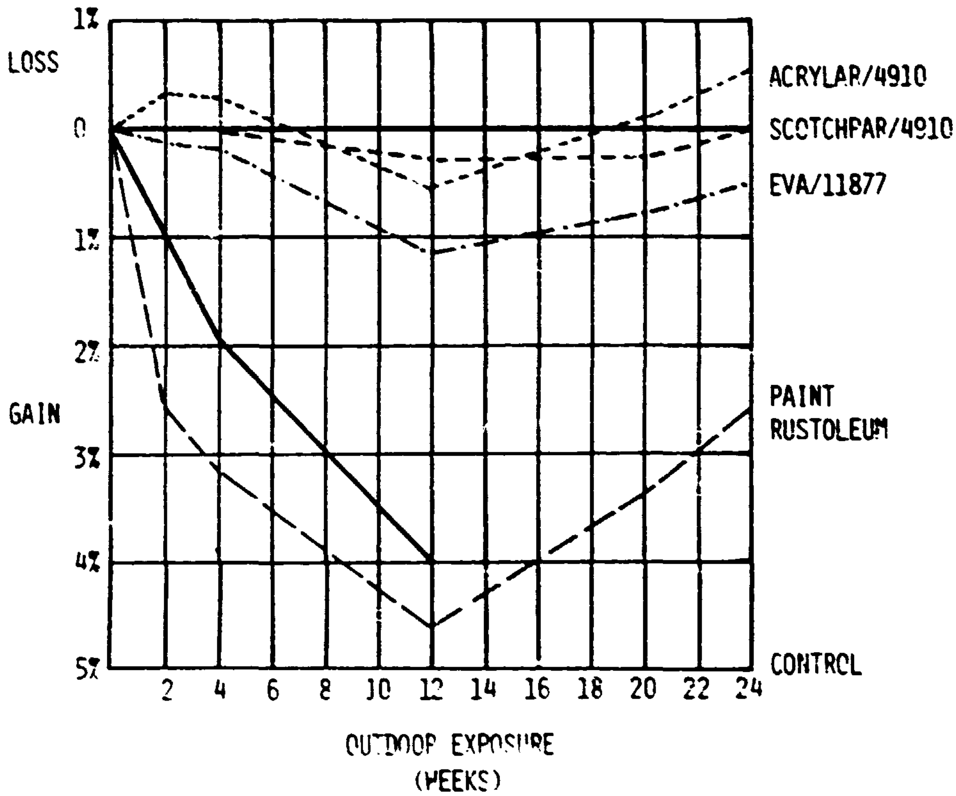
"SUPER DORLUX" - MASONITE CORPORATION

"MODULES" PREPARED WITH BUTYL EDGE SEAL AND
GASKET - SIX MONTHS OUTDOORS,
ENFIELD, CONNECTICUT

| COATING | ADHESIVE | % CHANGE MODULE | % CHANGE HARDBOARD |
|---|---|---|---|
| ACRYLAR | 3M 4910 | -.40 | -.53 |
| KORAD 63000 | 3M 4910 | -.58 | -.75 |
| PAINT (RUSTOLEUM) | - | +1.98 | +2.57 |
| 302 STAINLESS | 3M 4920 | -.03 | -.05 |
| ALUM. FOIL | 3M 4910 | +.07 | +.09 |
| SCOTCHPAR 20CP | 3M 4910 | +.03 | +.05 |
| EVA 9918 | A 11861 | +.36 | +.53 |
| TEDLAR, WHITE | 68070 | -.26 | -.34 |
| MELAMINE "SHOWER COATING" AND EVA 9918 WITH A 11861 | - | +2.56 | +3.26 |
| HARDBOARD | UNCOATED | - | +3.36 |

. NO SIGNS OF DELAMINATION OR EDGE SEAL DETERIORATION
. RAINFALL, 12.6 INCHES TOTAL
. BEST PERFORMANCE TO DATE WITH METAL FOIL COVERS
. BEST ORGANIC FILM, SCOTCHPAR POLYESTER

"SUPER DORLUX" MODULES PREPARED WITH BUTYL EDGE SEAL AND GASKET



## Soiling Effects

DECAY IN OPTICAL TRANSMISSION
SITE: ENFIELD, CONNECTICUT

| MATERIAL | % TRANSMISSION[A] | | |
|---|---|---|---|
| | CONTROL | 4 WEEKS | 8 WEEKS |
| PYREX GLASS | 92 | 90 | 90 |
| SODA LIME GLASS | 87 | 84 | 87 |
| TEDLAR 100BG30UT | 84 | 72 | 77 |
| RTV 615 | 79 | 65 | 65 |
| Q1-2577 | 74 | 65 | 64 |
| SYLGARD 184 | 82 | 81 | 54 |

A. DIRECT TRANSMISSION FROM 350 NM TO 900 NM.

JPL SOILING THEORY SUGGESTS THAT SOIL RESISTANT SURFACES HAVE THE FOLLOWING PROPERTIES

- HIGH SURFACE HARDNESS
- HYDROPHOBIC
- OLEOPHOBIC
- ION FREE
- LOW SURFACE ENERGY
- SMOOTH

## Antisoiling Experiments

SURFACE UNDER INVESTIGATION:

SUNADEX GLASS

3M ACRYLIC FILM, X-22417

TEDLAR 100BG30UT - DU PONT

SURFACE TREATMENTS UNDER INVESTIGATION:

3M FLUOROSILANE TREATMENT L-1668[A.]

PERFLUORODECANOIC ACID BASED COATING[A.]
DOW CORNING E-3820

OWENS ILLINOIS GLASS RESIN 650

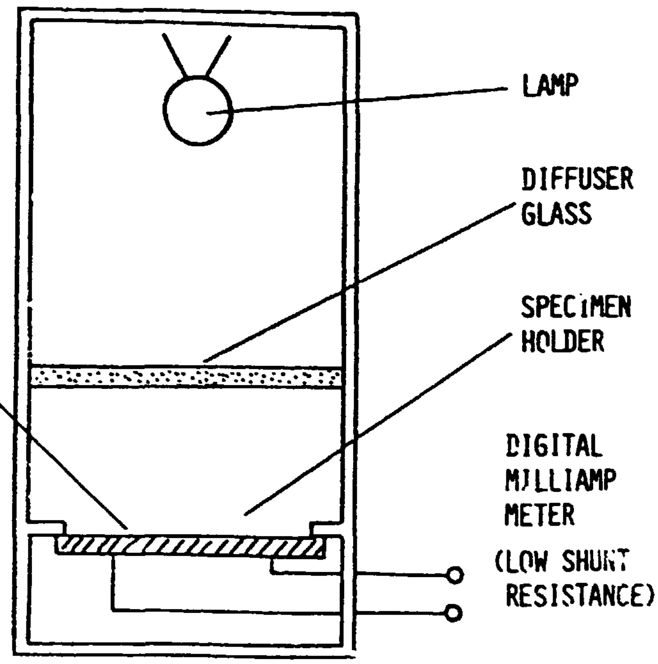
GENERAL ELECTRIC SHC - 1000

ROHM & HAAS WL-81 ACRYLIC COATING

A. ALSO USED WITH OZONE TREATMENT TO COUPLE TO ORGANIC SURFACES.

## Antisoiling Program

SHORT CIRCUIT MEASUREMENT DEVICE




$$\frac{\text{CURRENT W/SPECIMEN}}{\text{SHORT CIRCUIT CURRENT}} \times 100 = \%\ \text{CHANGE IN SHORT CIRCUIT CURRENT}$$

ORIGINAL PAGE IS OF POOR QUALITY

## Antisoiling Test Results

TEN MONTH EXPOSURE
ENFIELD, CONN.

| TREATMENT | SUNADEX | | ACRYLIC X-22417 | | TEDLAR 100 BG 30 UT | |
|---|---|---|---|---|---|---|
| | INITIAL | Δ% | INITIAL | Δ% | INITIAL | Δ% |
| CONTROL NO TREATMENT | 90.5 | -3.2 | 84.0 | -10.8 | 87.7 | -8.8 |
| L-1668 | 89.7 | -2.3 | 80.3 | -6.6 | 88.4 | -5.3 |
| L-1668/OZONE | A. | A. | 84.5 | -6.1 | 88.1 | -5.0 |
| PFDA E-3820 | 90.0 | -2.7 | 80.0 | -6.8 | 86.0 | -3.8 |
| PFDA E-3820/OZONE | A. | A. | 84.1 | -4.9 | 86.0 | -6.4 |
| GLASS RESIN 650 | 91.0 | -5.7 | 81.1 | -7.4 | 89.0 | -6.5 |
| SHC - 1000 | 91.9 | -4.5 | 82.1 | -7.6 | 89.0 | -5.6 |
| WL-81 | 90.7 | -5.1 | 83.6 | -6.3 | 87.7 | -5.2 |

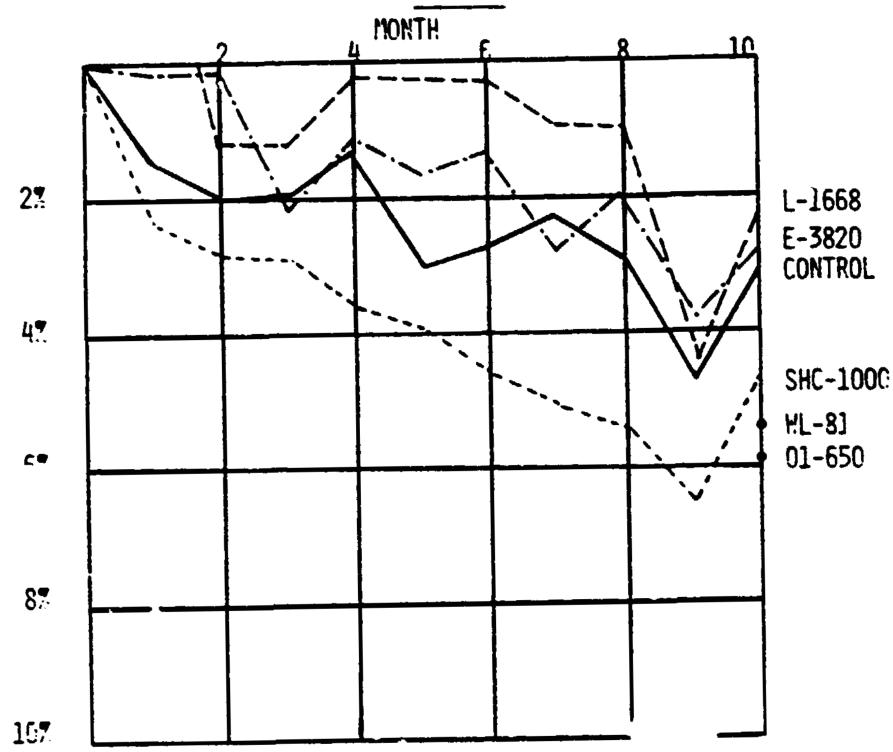
A. NOT PREPARED

## Antisoiling Experiments

TEN MONTHS EXPOSURE, ENFIELD, CONNECTICUT

% LOSS IN $I_{SC}$ WITH STANDARD CELL

TREATED SUNADEX GLASS



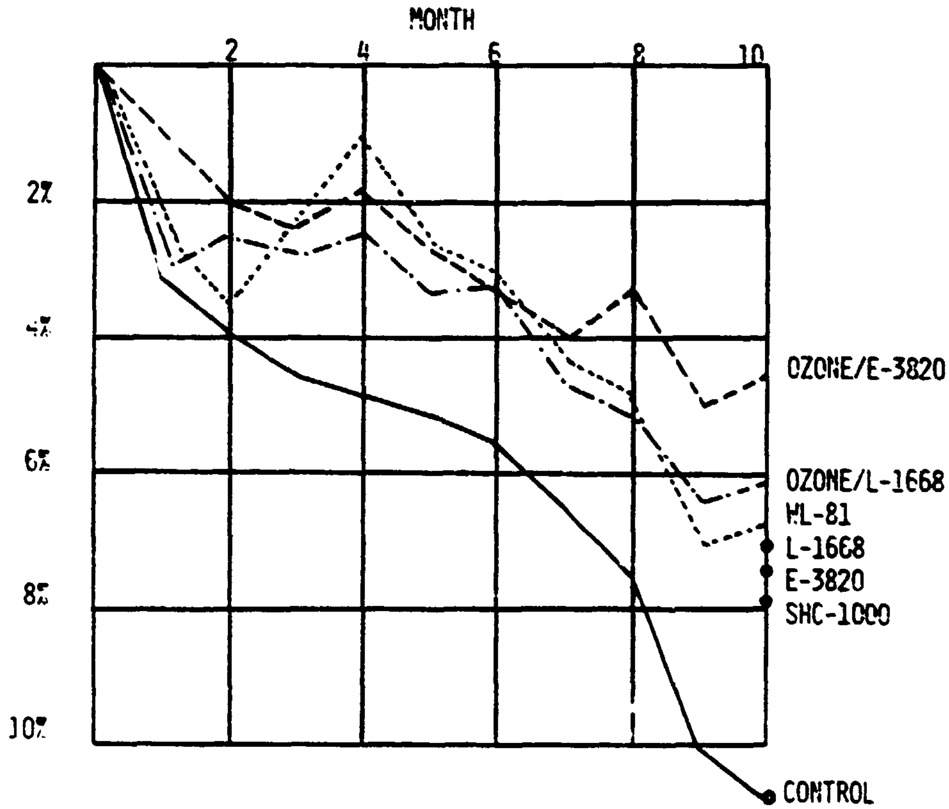

. BEST TREATMENT, L-1668

TEN MONTHS EXPOSURE, ENFIELD, CONNECTICUT

% LOSS IN $I_{SC}$ WITH STANDARD CELL

TREATED ACRYLAR

(SUPPORTED ON GLASS)




- BEST TREATMENT, OZONE WITH E-3829 (FLUOROSILANE)

## ENVIRONMENTAL ISOLATION TASK

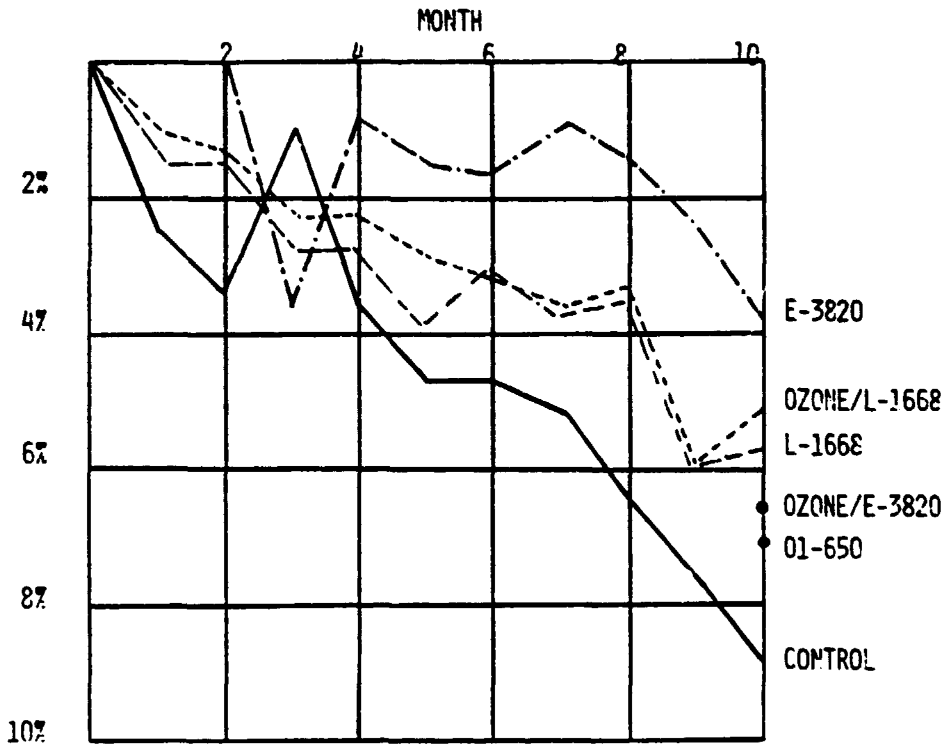
ORIGINAL PAGE IS OF POOR QUALITY

TEN MONTHS EXPOSURE, ENFIELD, CONNECTICUT

% LOSS IN $I_{SC}$ WITH STANDARD CELL

TREATED TEDLAR 100BG30OUT

(SUPPORTED ON GLASS)




BEST TREATMENT, E-3820

ENVIRONMENTAL ISOLATION TASK



GENERAL OBSERVATIONS:

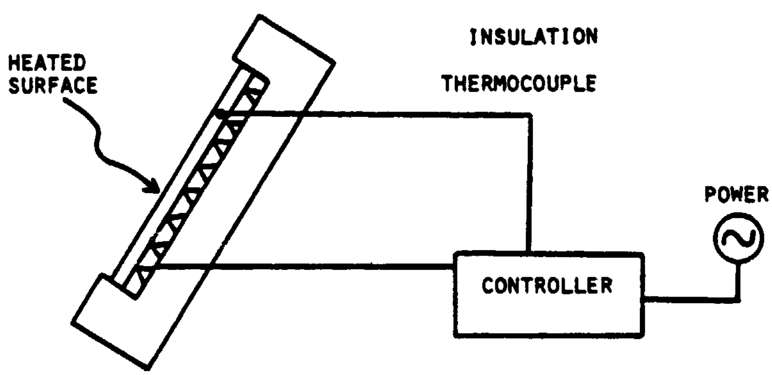
- SUNADEX HAS BEST CONTROL VALUES (-3.0%)
- SUNADEX: BEST COATING, L-1668 (-0.5%)
- TEDLAR: BEST COATING, E-3820 (-1.5%)
- ACRYLAR: BEST COATING, OZONE + E-3820 (-2.4%)
- GOOD CORRELATION WITH NATURAL "CLEANING" CONDITIONS

NEW MATERIALS:

- NEW FLUOROSILANE (SPRINGBORN):
  PERFLUORO-OCTYL TRIETHOXYSILANE
- REACTIVE POLYMER SURFACE TREATMENT (SPRINGBORN):
  PERFLUOROBUTYL ACRYLATE COPOLYMERIZED
  WITH DOW CORNING Z-6030 SILANE

## Accelerated Aging Test Program: Outdoor Photothermal Aging

- USE NATURAL SUNLIGHT, AVOIDS SPECTRAL DISTRIBUTION PROBLEMS WITH ARTIFICIAL LIGHT SOURCES
- USES TEMPERATURE TO ACCELERATE THE PHOTOTHERMAL REACTION
- INCLUDES DARK CYCLE REACTIONS
- INCLUDES DEW/RAIN EXTRACTION
- SILICONE RUBBER HEATERS - IN OPERATION ONLY DURING SUNLIT HOURS



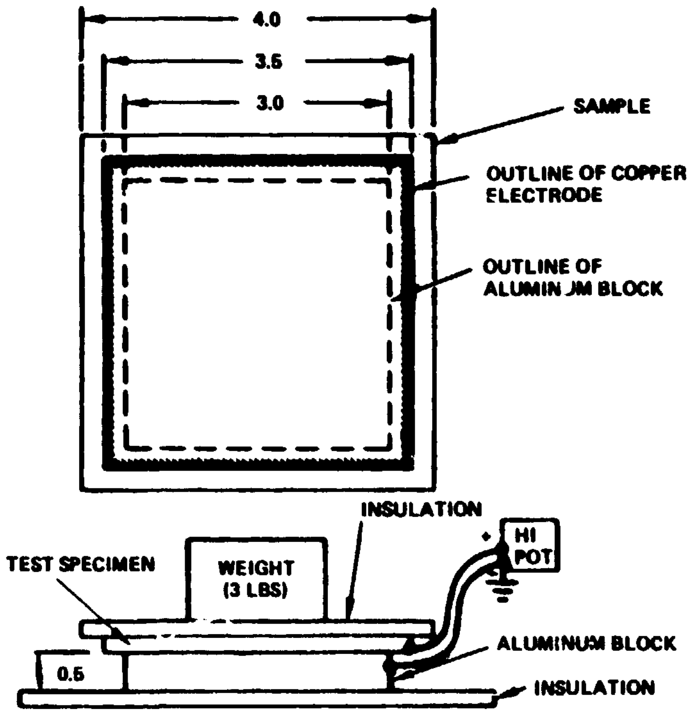

- TEMPERATURES OF INTEREST, $70^{o}$, $90^{o}$, $110^{o}$ C
- TEST MATERIALS:
  - 4 POTTANTS: EVA, EMA, BA, PU
  - 3 OUTER COVERS: SUNADEX, TEDLAR, ACRYLIC
  - COMBINATIONS OF POTTANTS/OUTER COVERS
- TESTS:
  - DIELECTRIC STRENGTH
  - CHEMICAL INERTNESS (COPPER CORROSION)
  - OPTICAL TRANSMISSION
  - STANDARD CELL OUTPUT
  - GEL CONTENT
  - YOUNG'S MODULUS
  - TENSILE STRENGTH
  - ULTIMATE ELONGATION
- DUPLICATE SPECIMENS - PHOENIX AND FLORIDA

# ENCAPSULANT DESIGN ANALYSIS AND VERIFICATION

SPECTROLAB, INC.

C.P. Minning (Hughes Aircraft Co.)

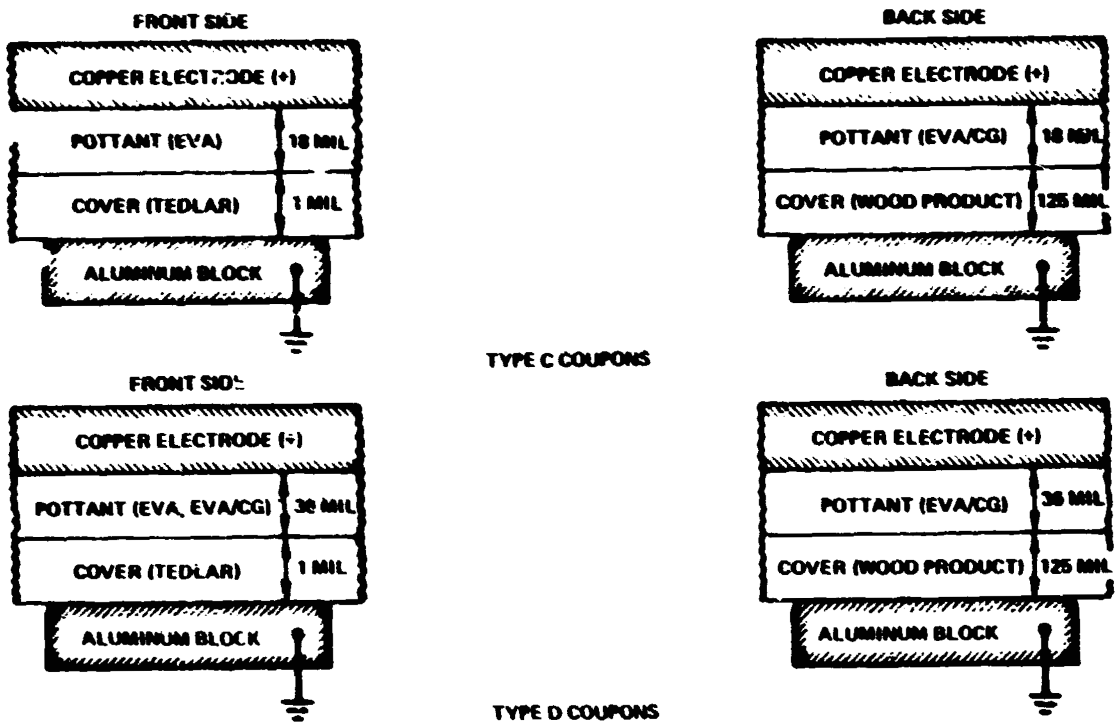
## Electrical Test Setup



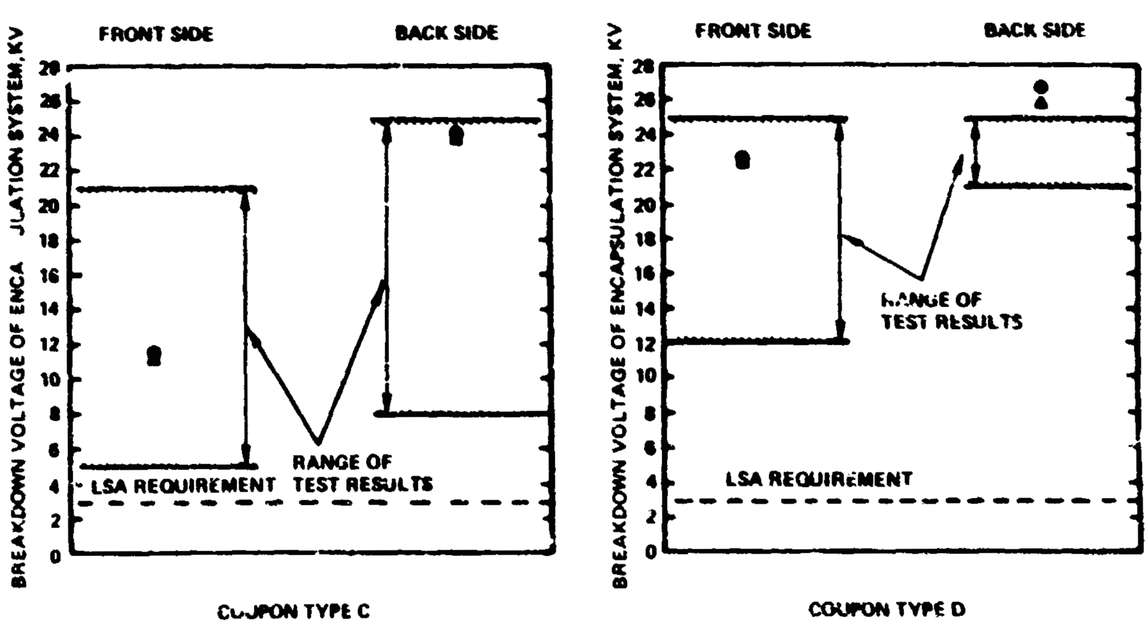
ORIGINAL PAGE IS
OF POOR QUALITY

## ENVIRONMENTAL ISOLATION TASK

### Electrical Isolation Models (Typical)

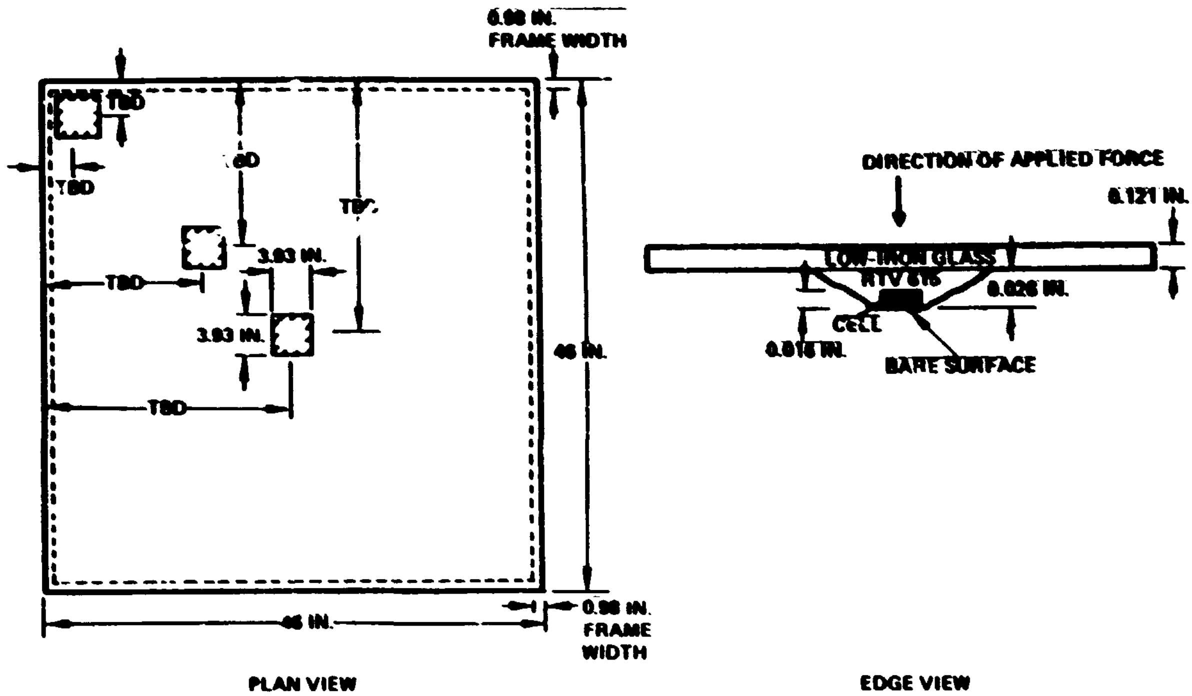



### Electrical Isolation Test Results

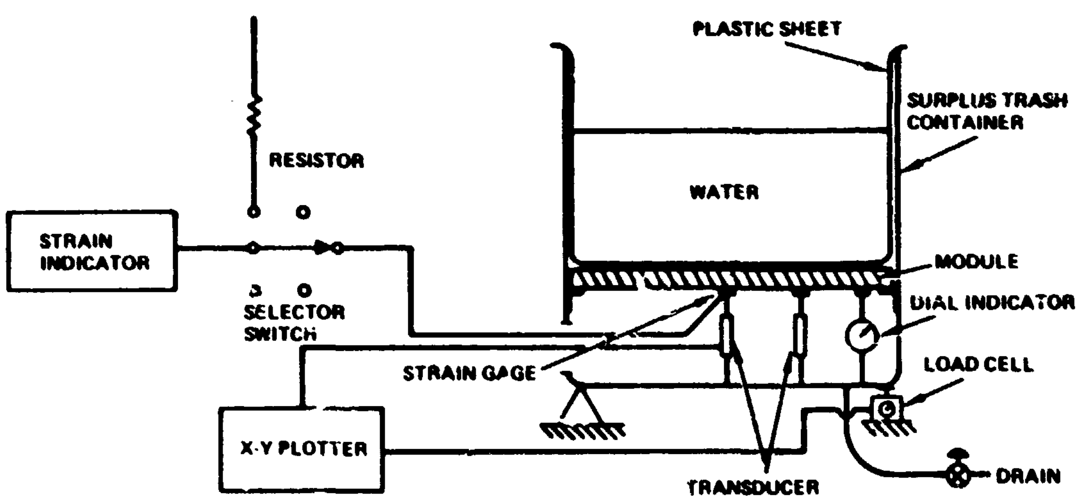


ORIGINAL PAGE IS
OF POOR QUALITY

## Typical Test Article: Structural/Deflection Test




## Structural Deflection Test Setup



ORIGINAL PAGE IS
OF POOR QUALITY

## Structural Deflection Test Results

LOAD-BEARING MEMBER DEFLECTION AND STRESS

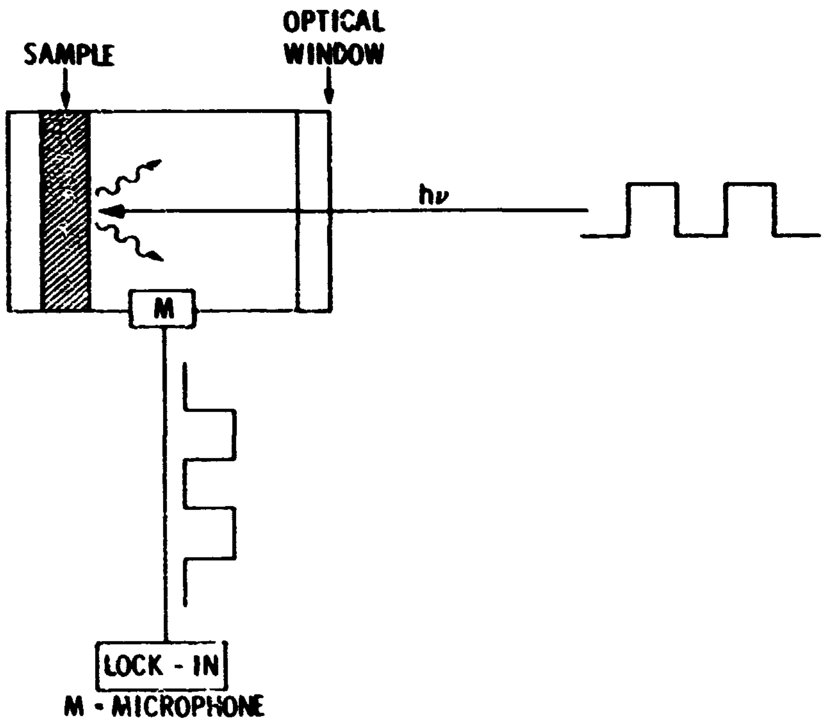
| TEST MODULE | DESCRIPTION | DEFLECTION, INCHES | | STRESS, PSI | |
|---|---|---|---|---|---|
| | | TEST | ANALYSIS | TEST | ANALYSIS |
| SDM –1 | GLASS SUPERSTRATE | 0.615 | 0.67 | 3216 | 5381 |
| 2 | GLASS SUPERSTRATE | 0.62 | 0.65 | 4571 | 4946 |
| 3 | GLASS SUPERSTRATE | 0.61 | 0.67 | 2571 | 5100 |
| 4 | GLASS SUPERSTRATE | 0.58 | 0.65 | 2749 | 4236 |
| 5 | PLAIN WOOD SUBSTRATE | 1.42 | 1.33 | 817 | 752 |
| 6 | PLAIN WOOD SUBSRTATE | 1.36 | 1.27 | 766 | 741 |
| 7 | RIBBED WOOD SUBSTRATE | FAILURE | – | – | – |
| 8 | STEEL SUBSTRATE | 0.42 | 0.5 | 2357 | 4395 |
| 9 | RIBBED WOOD SUBSTRATE | 0.37 | 0.36 | NA | NA |

# PHOTOACOUSTIC TECHNIQUE

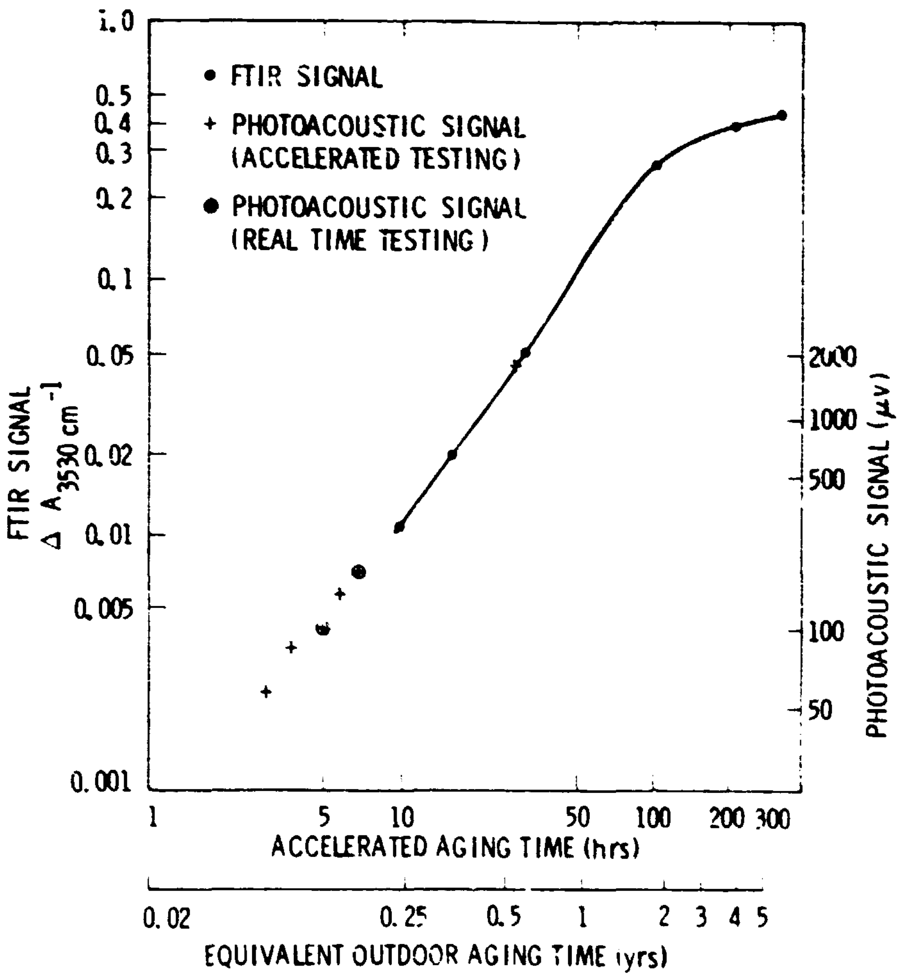
JET PROPULSION LABORATORY

R.H. Liang

## Photoacoustic Setup



## Formation of (OH) as a Function of Accelerated and Real-Time Aging



# MINIMODULE ENCAPSULANT FIELD TESTING

JET PROPULSION LABORATORY

P. Frickland

## Summary of Minimodule Temperature and Humidity-Freeze Testing

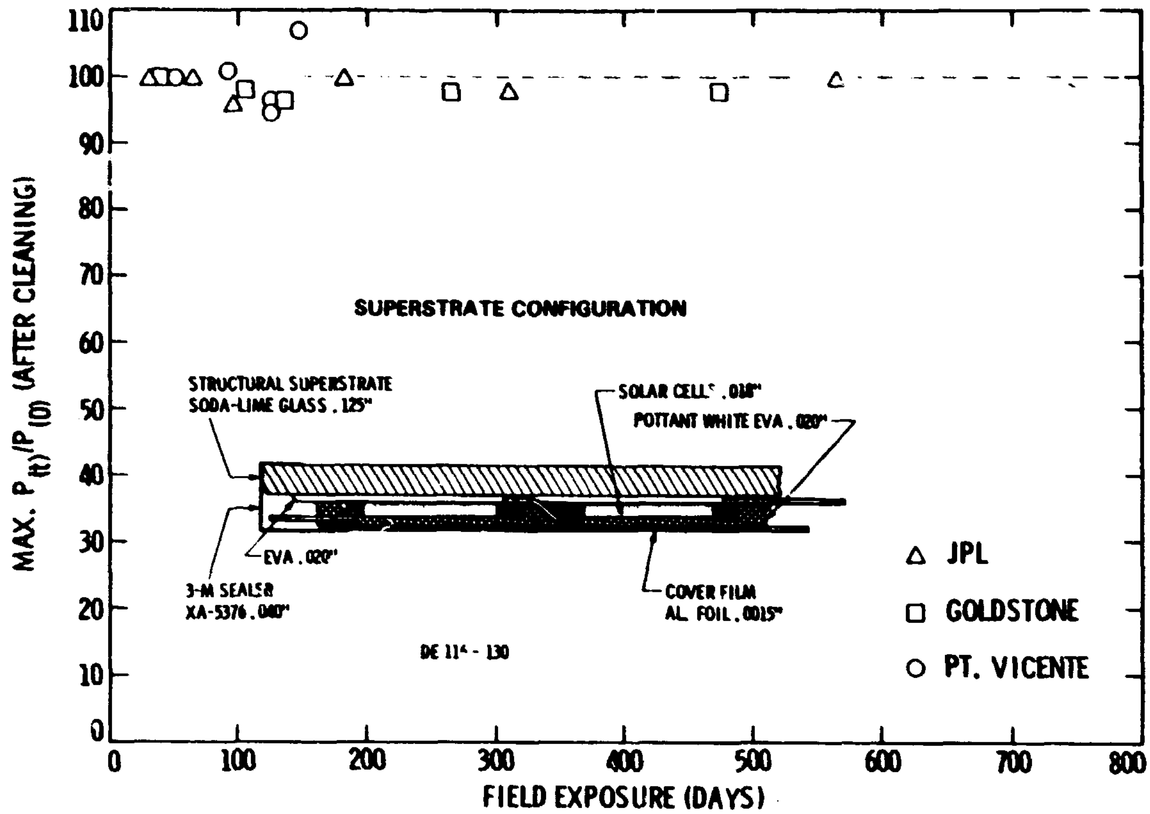
| SUBSTRATE | $\Delta P_{(T)}/P_{(0)}$ % TEMP | HUMID/FREEZE |
|---|---|---|
| KORAD/EVA/GALVANIZED STEEL (DE 131-145) | - 4 | - 6 |
| TEDLAR/EVA/GLASS REINFORCED CONCRETE (MB 110-124) | - 0 | -11 |
| KORAD/EVA/SUPER DORLUX (DE 101-115) | -25 | -59 |
| **SUPERSTRATE (GLASS)** | | |
| SODA-LIME GLASS/POLYURETHANE (PW 101-115) | + 5 | + 1 |
| SODA-LIME GLASS/POLYURETHANE/ACMETITE (PW 116-130) | + 2 | + 1 |
| SODA-LIME GLASS/EVA/WHITE EVA/CRANEGLASS/AL FOIL (DE 116-130) | - 4 | - 6 |
| SUNADEX GLASS/EVA/ACMETITE (CE 131-145) | + 2 | + 1 |
| SUNADEX GLASS/EVA/CRANEGLASS/ACMETITE (CE 116-130) | - 2 | - 1 |
| SUNADEX GLASS/EVA/CRANEGLASS/MYLAR (CE 101-115) | - 2 | - 2 |
| SUNADEX GLASS/RTV SILICONE/CRANEGLASS/ACMETITE (GE 101-105) | + 1 | + 2 |
| 7070 BOROSILICATE GLASS (ESB)/EVA/ACMETITE (SE 101-110) | + 1 | 0,-100 |

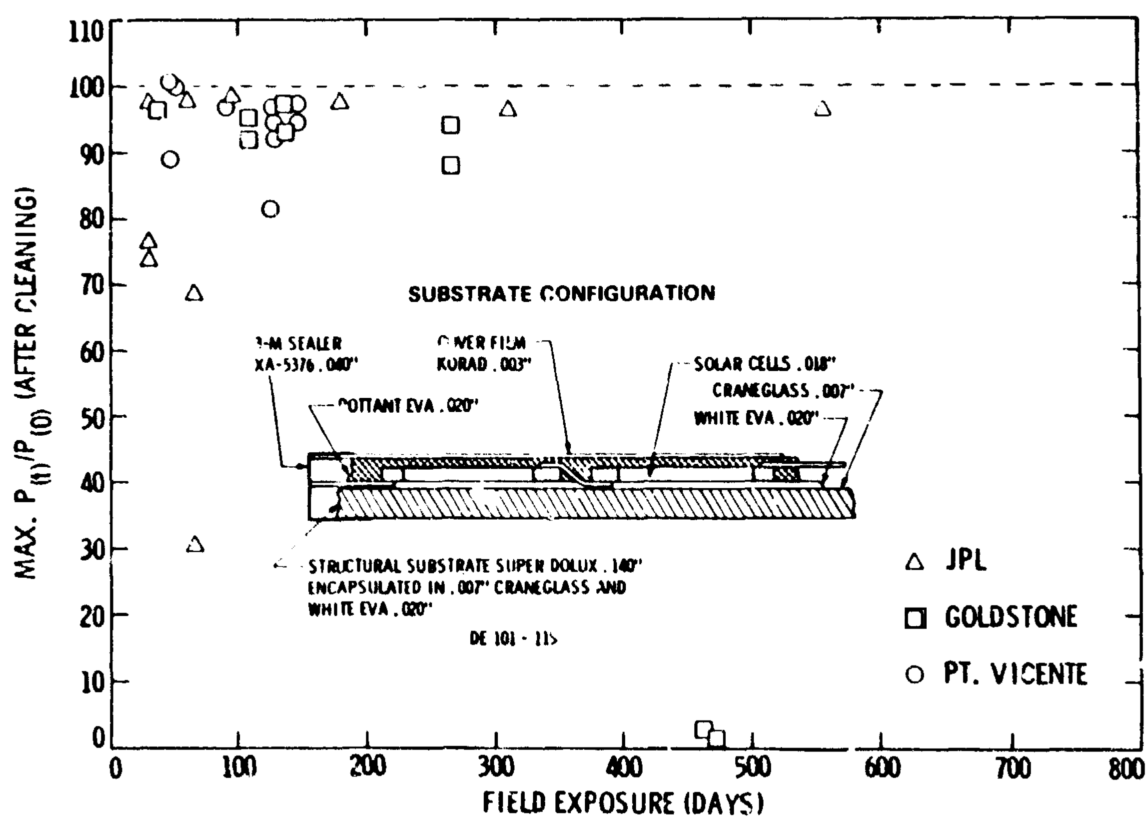
## Summary of Minimodule Hail Testing

| SUBSTRATE | RESULTS |
|---|---|
| KORAD/EVA/GALVANIZED STEEL (DE 131-145) | OK |
| TEDLAR/EVA/GLASS REINFORCED CONCRETE (MB 110-124) | OK |
| KORAD/EVA/SUPER DORLUX (DE 101-115) | OK |
| **SUPERSTRATE (GLASS)** | |
| SODA-LIME GLASS/POLYURETHANE (PW 101-115) | OK |
| SODA-LIME GLASS/POLYURETHANE/ACMETITE (PW 116-130) | OK |
| SODA-LIME GLASS/EVA/WHITE EVA/CRANEGLASS/AL FOIL (DE 116-130) | OK |
| SUNADEX GLASS/EVA/ACMETITE (CE 131-145) | OK |
| SUNADEX GLASS/EVA/CRANEGLASS/ACMETITE (CE 116-130) | * |
| SUNADEX GLASS/EVA/CRANEGLASS/MYLAR (CE 101-115) | OK |
| SUNADEX GLASS/RTV SILICONE/CRANEGLASS/ACMETITE (GE 101-105) | OK |
| 7070 BOROSILICATE GLASS (ESB)/EVA/ACMETITE (SE 101-110) | BAD (4 @ 25 MPH) |

* CRACKED AT EDGE ONLY, 3RD IMPACT 52 MPH

ORIGINAL PAGE IS OF POOR QUALITY



ORIGINAL PAGE IS
OF POOR QUALITY