ENCAPSULATION MATERIALS RESEARCH

SPRINGBORN LABORATORIES, INC.

P. Willis

PHASE I
IDENTIFY AND DEVELOP LOW COST
MODULE ENCAPSULATION MATERIALS
- POTTANTS
- COVER FILMS
- SUBSTRATES
- ADHESIVES/PRIMERS
- ANTI-SoILING TREATMENTS

PHASE II
MATERIALS RELIABILITY
- AGING AND LIFE ASSESSMENT
- ADVANCED STABILIZERS
- CHEMICAL DIAGNOSTICS
- FLAMMABILITY
- ELECTRICAL ISOLATION

PHASE III
PROCESS SENSITIVITY
- INTERRELATIONSHIPS OF
  - FORMULATION VARIABLES
  - PROCESS VARIABLES
- MANUFACTURING YIELD ANALYSIS
  (PROCESS DEVELOPMENT SECTION)
Module Components

- SURFACE
- OUTER COVER (OR GLASS)
- POTTANT
- BACK COVER (OR SUBSTRATE)
- GASKET/SEALANT

CURRENT EMPHASIS ON MATERIALS AND MODULE PERFORMANCE CHARACTERISTICS

- DETERMINE CURRENT LEVEL OF PERFORMANCE
- ENHANCE PERFORMANCE (E.G. REFORMULATION)
- SERVICE LIFE PROGNOSIS

PERFORMANCE CRITERIA

- ENVIRONMENTAL DEGRADATION
- ADHESIVE BOND DURABILITY
- ELECTRICAL INTEGRITY
- FLAMMABILITY
Module Flammability

- Most modules constructions not passing UL-90 burning brand test
- Mechanism: Appears to be rupture of the back cover with the evolution of burning gasses
- Modules can burn but must not serve as an ignition source to other structures
- Modules with Kapton back covers (high strength) pass test due to ability to retain combustible gasses

Kapton is very expensive
- Inexpensive high strength high temperature back cover needed
Module Flammability

GOAL:
- PREVENT SPREAD OF FLAME
- PASS UL-790

APPROACHES:

(1) HIGH STRENGTH HEAT RESISTANT BACK COVERS
   - CERAMIC PAPER
   - POLYMER FILM LAMINATES WITH GLASS SCRM REINFORCEMENT
   - METAL FOILS
   - RESIN IMPREGNATED GLASS CLOTH

(2) REDUCTION OF COMBUSTIBLE MATERIALS
   - THINNING OF POTENT LAYER

(3) FIRE RETARDANT ADDITIVES
   - INERT DILUENTS (TALC, CALCIUM CARBONATE)
   - RELEASE OF WATER WITH HEAT ALUMINA TRHYDRATE (35% WATER)
   - FIRE RETARDANTS (FREE RADICAL TRAPS)
     - ANTIMONY OXIDE, ZINC BORATE
     - BROMINATED ORGANICS
     - ORGANIC PHOSPHATES

(4) COMBINATION OF ALL THREE
EVALUATION OF CANDIDATE TECHNIQUES

CONVENTIONAL:
- UL-94 VERTICAL BURN TEST
- ASTM E-262 FLAME SPREAD INDEX
- ASTM D-2863 LIMITING OXYGEN INDEX

FOR BACK COVERS:
- CONSTRUCT SPECIAL APPARATUS

- DETERMINE BURST STRENGTH AS FUNCTION OF TEMPERATURE AND PRESSURE
- CORRELATE TO ACTUAL EFFECTIVENESS UNDER FIRE CONDITIONS
- DETERMINE ADD-ON COST FOR IMPROVEMENT IN FIRE RATING
- RECOMMEND CANDIDATES FOR UL-790 TESTING
RELIABILITY PHYSICS

Electrical Isolation

- POTTANTS AND COVER FILMS SERVE AS ELECTRICAL INSULATION
- NEED TO KNOW THICKNESS REQUIRED FOR VOLATAGE STANDOFF
- VARIATION WITH TEMPERATURE, ABSORBED WATER
- NEED TO KNOW VARIATION DIELECTRIC STRENGTH WITH AGING:
  LIGHT, HEAT, HUMIDITY, FIELD STRESS

METHOD:

- USE DC DIELECTRIC TEST APPARATUS
  TIP TO TIP SYMMETRIC ELECTRODES
- SPECIFIED RATE OF RISE
- PLOT AVERAGE BREAKDOWN VOLTAGE, V_A VS THICKNESS
- STRAIGHT LINE RELATIONSHIP:
  SLOPE CONSIDERED TO BE THE INTRINSIC DIELECTRIC STRENGTH, dV/dT
- MEASUREMENTS TO DATE:
  EVA dV/dT = 3.65 kV/MIL
- REMEASURE dV/dT:
  - THERMAL AGING
  - WATER ABSORPTION
  - ENVIRONMENTAL EXPOSURE
  - FIELD STRESS AGING
- RECALCULATE THE REQUIRED INSULATION THICKNESS
  FOR SERVICE LIFE OF THE MODULE
### Adhesion Experiments

**SELF-PRIMING FORMULATIONS (TO SUNADEX GLASS)**

<table>
<thead>
<tr>
<th>PRIMANT/PRIMER</th>
<th>LEVEL (PHR)</th>
<th>CONTROL</th>
<th>12 MONTHS STORAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVA A9918</td>
<td>0.25</td>
<td>42</td>
<td>31</td>
</tr>
<tr>
<td>Z-6030</td>
<td>0.05</td>
<td>29</td>
<td>20</td>
</tr>
<tr>
<td>EVA 15295/</td>
<td>0.25</td>
<td>31</td>
<td>28</td>
</tr>
<tr>
<td>Z-6030</td>
<td>0.05</td>
<td>10.9</td>
<td>5</td>
</tr>
<tr>
<td>EMA 15257/</td>
<td>0.25</td>
<td>57.4</td>
<td>41</td>
</tr>
<tr>
<td>Z-6030</td>
<td>0.05</td>
<td>49.0</td>
<td>26</td>
</tr>
</tbody>
</table>

*BCNS ALSO STABLE TO WATER IMMERSION AND BOILING WATER*

- **STABLE TO STORAGE CONDITIONS (12 MO. TO DATE)** AT 0.25 PHR LEVEL, .05 PHR NOT AS STABLE
- **NOW COMMERCIALY AVAILABLE (SPRINGBORN)**
  - EVA A9918-P (LUPERSOL 101 CURE)
  - EVA 15295-P (TBEC CURE)

- **WORKING ON INTERNAL PRIMING FOR CELL STRING AND METALLIZATION (MORE DIFFICULT TO PRIME)**
RELIABILITY PHYSICS

CONTINUED PRIMER STUDIES:

- EVALUATE THE THREE "BASIC" PRIMERS -
  DR. PLUEDDEMANN - DOW CORNING
  - POLYMER/METAL
  - POLYMER/INORGANIC
  - POLYMER/ORGANIC

- METAL PRIMER (ALUMINUM) RECOMMENDATIONS
  DR. JIM BOERIO - UNIVERSITY OF CINCINNATI

ADHESION DIAGNOSTICS:

- HOW DURABLE ARE ADHESIVE BONDS?
  UNDER WHAT CONDITIONS?

- SUCCESSFUL SPECTROSCOPIC EXAMINATION OF GLASS/
  PRIMER INTERFACE - DR. JACK KOENIG -
  CASE WESTERN RESERVE

- EVA COMPOUNDED WITH HIGH LOADINGS OF SILANE
  TREATED GLASS BEADS
  - SPECIMENS AT CASE WESTERN FOR "DRIFT"
    ANALYSIS (CHEMICAL)
  - IDENTICAL SPECIMENS AT SPRINGBORN FOR
    MECHANICAL ANALYSIS
  - HYDROLYTIC AGING
  - CORRELATE CHEMICAL OBSERVATIONS WITH
    MECHANICAL PERFORMANCE
  - DETERMINE DEGRADATION RATES
  - ASSESS SERVICE LIFE
Accelerated Aging

OUTDOOR PHOTOTHERMAL AGING DEVICES
(OPT)

- USE NATURAL SUNLIGHT, AVOIDS SPECTRAL DISTRIBUTION PROBLEMS WITH ARTIFICIAL LIGHT SOURCES
- USE TEMPERATURE TO ACCELERATE THE PHOTO- THERMAL REACTION
- INCLUDES DARK CYCLE REACTIONS
- INCLUDES DEW/RAIN EXTRACTION
- INTENDED PRIMARILY FOR MODULE EXPOSURE
- EXTRAPOLATE EFFECTS TO LOWER TEMPERATURES
RELIABILITY PHYSICS

- MODULE EXPOSURE: OPT 105°C, 7,000 HRS
- ALL SHOW SEVERE COPPER REACTION
- BEST PERFORMANCE: EVA-ADVANCED STABILIZER TBEC, UV-2098, TINUVIN 770
  VIRTUALLY NO DEGRADATION APPARENT
- CONSPICUOUS DEGRADATION IN OTHERS
- GLASS FRACTURE - THERMAL SHOCK
- MODULE EXPOSURE: OPT 70°C, 7000 HRS.
- SOME COPPER REACTION W/EVA 9918
- NO OTHER EFFECTS NOTICEABLE
- USEFUL FOR EVALUATING CANDIDATE FORMULATIONS - COMPARISON
- EVALUATES WHOLE MODULES
- DETERMINE UPPER LEVEL SERVICE TEMPERATURES
- MODELLING:
  - ARRHENIUS: LOG P VS. 1/K^0
  - PREDICT SERVICE LIFE BY EXTRAPOLATION TO LOWER TEMPERATURES
  - TIME TO ONSET OF DEGRADATION (INDUCTION PERIOD)
  - PROBABILITY DISTRIBUTION-FAILURE
- EXAMPLE: POLYPROPYLENE - INDUCTION TIME

TIME, HOURS

VT(°M) SHOWN AS DEGREES CENTIGRADE
Advanced Stabilizers

RELIABILITY PHYSICS

1. **LIGHT (UV)**
   - Absorption
   - Excited Species (Activated Ketones)
   - Radicals
   - Free Radical Scavengers
   - Hydroperoxide Decomposers

2. **Auto-Catalytic Degradation**
   - Quenchers: Strongly Colored - Not Used
   - Long Term Stabilizers:
     - Oxidatively Stable
     - Non-Fugitive
   - UV-2098 (American Cyanamide) Best Screener
     Found To Date (Co-Reactive Benzopheneone)
   - Hindered Amine Light Stabilizers (HALS)
     Free Radical Traps and Hydroperoxide Decomposition
   - Combination of Screener and HALS Best Stabilizer Package

---

155
RELIABILITY PHYSICS

CANDIDATE HINDFRED AMINES (HALS)

- HIGH EFFICIENCY FROM REGENERATIVE CHEMISTRY:
  ACTIVE SPECIES RECYCLES - NON SACRIFICIAL

- EVALUATION OF CANDIDATES:
  - EVA, TBEC CURE, 0.1% HALS
  - % ELONGATION VERSUS TIME
  - OPT DEVICE, 90 °C

○ CONTROL
△ TINUVIN 770
▲ CHIMASORB 944

PERCENT ELONGATION

EXPOSURE, HOURS

- FAILURE: LOSS OR CONSUMPTION OF CHEMISTRY?
  NEED FOR ANALYTICAL METHOD
- CYASORB UV-336 (CYANAMIDE) CLEARLY BETTER
- SYSTEM EVALUATION: EVA/TBEC/UV-2096/UV-3346
  MODULES, ADHESION, FLAMMABILITY, ETC.
Antisoiling Treatments

SURFACE CHEMISTRY:
- HARD
- SMOOTH
- HYDROPHOBIC
- OLEOPHOBIC
- ION FREE
- LOW SURFACE ENERGY

SURFACE INVESTIGATED:
- SUNADEX GLASS
- TEDLAR (100 BG 30 UT)
- ACRLAR (ACRYLIC FILM)

TREATMENTS REMAINING:
- L-1668 FLUOROSILANE (3M)
- E-3820 PERFLUORODECANOIC ACID/SILANE (DOW CORNING)
- STILL EFFECTIVE AT 38 MONTHS OUTDOOR EXPOSURE
- RESULTS IN IMPROVED POWER OUTPUT
- FLUOROALKYL SILANE CHEMISTRY APPEARS TO BE MOST EFFECTIVE
Soiling Experiments

THIRTY-TWO MONTHS EXPOSURE
ENFIELD, CONNECTICUT

% LOSS IN $I_{SC}$ WITH STANDARD CELL TREATED
TEDLAR 100BG300UT
(SUPPORT ON GLASS)

38 MONTHS EXPOSURE

--- CONTROL, NO COATING
--- E-3920 COATING (BEST)

ESTIMATED AVERAGE POWER IMPROVEMENT, 3.8%
THIRTY-TWO MONTHS EXPOSURE
ENFIELD, CONNECTICUT

% LOSS IN $I_{sc}$ WITH STANDARD CELL TREATED ACRYLAR
(SUPPORTED ON GLASS)

38 MONTHS EXPOSURE

CONTROL, NO TREATMENT

OZONE WITH E-3820 (BEST)

ESTIMATED AVERAGE POWER IMPROVEMENT, 3.3%
RELIABILITY PHYSICS

THIRTY-TWO MONTHS EXPOSURE
ENFIELD, CONNECTICUT

% LOSS IN $I_{sc}$ WITH STANDARD CELL TREATED
SUNDEX GLASS

38 MONTHS EXPOSURE

---

CONTROL, NO TREATMENT

E-3820 (BEST)

RAINFALL, INCHES

ESTIMATED AVERAGE POWER IMPROVEMENT, 1%
Antisoiling Coatings

- STILL EFFECTIVE AFTER THREE YEARS OUTDOOR EXPOSURE
- PERMANENCE APPEARS TO BE GOOD
- POSSIBILITY FOR IMPROVED PERFORMANCE BY INCREASING SOIL REPELLENCY

NEW CANDIDATE(S):
- LOWEST SURFACE ENERGY EVER REPORTED: POLYMER OF PERFLUORO-OCTYL METHACRYLATE
  \[ \gamma_c = 10.6 \text{ dyne cm}^{-1} \]
- REACT WITH TRIMETHOXY HYDROGEN SIL-NE TO FORM ADDUCT WITH GLASS-REACTIVE GROUP
- EVALUATE IN SOILING TESTS
RELIABILITY PHYSICS

Outer Covers (Substrate Design)

- LOW COST UV SCREENING FILMS COMMERCIALLY AVAILABLE
- PROBLEMS: SHRINKAGE, STABILIZER EXTRACTION ADHESION, WEATHER STABILITY
- POTTANTS APPEAR TO HAVE GOOD STABILITY
- NON-SCREENING CANDIDATE FILMS CLEAR, WEATHERABLE, BONDABLE?

<table>
<thead>
<tr>
<th>FILM</th>
<th>REF. INDEX</th>
<th>% T</th>
<th>COST $/FT²/MIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEFZEL</td>
<td>1.403</td>
<td>85.6</td>
<td>0.128</td>
</tr>
<tr>
<td>KAYHAR</td>
<td>1.420</td>
<td>88.8</td>
<td>0.055</td>
</tr>
<tr>
<td>HALAR</td>
<td>1.40</td>
<td>85.3</td>
<td>0.096</td>
</tr>
<tr>
<td>FFA</td>
<td>1.30</td>
<td>88.4</td>
<td>0.123</td>
</tr>
<tr>
<td>FEP</td>
<td>1.34</td>
<td>93.6</td>
<td>0.109</td>
</tr>
</tbody>
</table>

- FEP MAY BE GOOD CHOICE:
  - HIGH TRANSPARENCY
  - OUTSTANDING WEATHERABILITY
  - MAY IMPROVE OPTICAL THROUGHPUT BY 2% DUE TO OPTICAL COUPLING
  - REQUIRES PRIMER TECHNOLOGY
  - WILL BE EVALUATED IN MODULE FABRICATION AND OUTDOOR EXPOSURE EXPERIMENTS
Conclusions

- OUTDOOR PHOTOTHERMAL AGING DEVICES (OPT)
- BEST ACCELERATED AGING METHOD DISCOVERED YET
- SIMULATES WORST CASE FIELD CONDITIONS
- EVALUATE FORMULATIONS
- EVALUATE MODULE PERFORMANCE
- POSSIBILITY FOR LIFE ASSESSMENT

AVOID METALLIC COPPER EXPOSURE

- SELF PRIMING FORMULATIONS HAVE GOOD STORAGE STABILITY AT 0.25 PHR

STABILIZERS - ENHANCED PERFORMANCE
- UV-2098 UV SCREENER
- UV-3346 HINDERED AMINE (HALS)

SOIL RESISTANCE TREATMENTS STILL EFFECTIVE
Future Work

- FLAMMABILITY: FIRE RETARDANTS AND FLAME RESISTANT WORK COVERS

- ELECTRICAL INTEGRITY: DIELECTRIC STRENGTH VERSUS AGING OF ENCAPSULATION MATERIALS

- ADHESION DIAGNOSTICS AND SERVICE LIFE ASSESSMENT

- MODULE EVALUATION: EVA POTTANT WITH ADVANCED STABILIZER PACKAGE

- NEW ANTI-SOILING CONCEPTS

- MODULE SERVICE LIFE ASSESSMENT

  (PHASE III)

- PROCESS AND MANUFACTURING VARIABLES