N85-32407

ENCAPSULATION MATERIALS RESEARCH

SPRINGBORN LABORATORIES, INC.

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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

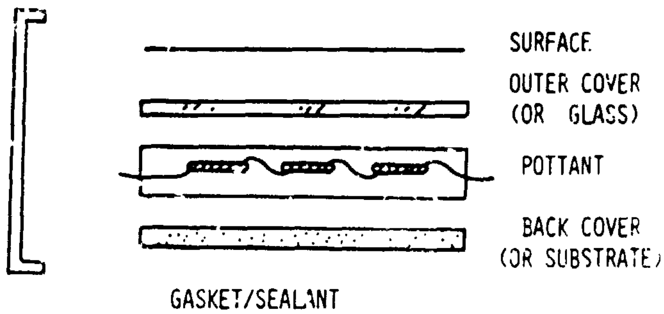
PHASE III

PROCESS SENSITIVITY

- INTERRELATIONSHIPS OF
    - FORMULATION VARIABLES
    - PROCESS VARIABLES
- MANUFACTURING YIELD ANALYSIS

(PROCESS DEVELOPMENT SECTION)

Module Components



CURRENT EMPHASIS ON MATERIALS AND MODULE PERFORMANCE CHARACTERISTICS

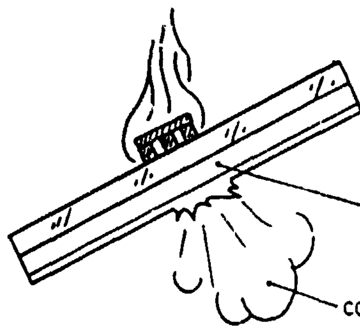
- DETERMINE CURRENT LEVEL OF PERFORMANCE
- ENHANCE PERFORMANCE (E.G. REFORMULATION)
- SERVICE LIFE PROGNOSIS

PERFORMANCE CRITERIA

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

Module Flammability

- MOST MODULES CONSTRUCTIONS NOT PASSING UL-790 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 SCRIM REINFORCEMENT
- METAL FOILS
- RESIN IMPREGNATED GLASS CLOTH

(2) REDUCTION OF COMBUSTIBLE MATERIALS

- THINNING OF POTTANT LAYER

(3) FIRE RETARDANT ADDITIVES

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

(4) COMBINATION OF ALL THREE

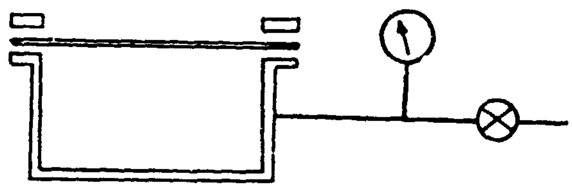
EVALUATION OF CANDIDATE TECHNIQUES

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

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)

POTTANT/PRIMER	LEVEL (PHR)	BOND STRENGTH, LBS/IN CONTROL*	12 MONTHS* STORAGE
EVA A9918	0.25	42	31
Z-6030	0.05	29	20
EVA 15295/	0.25	31	28
Z-6030	0.05	10.9	5
EMA 15257/	0.25	57.4	41
Z-6030	0.05	49.0	26

*BONDS 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 COMMERCIALLY 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)

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

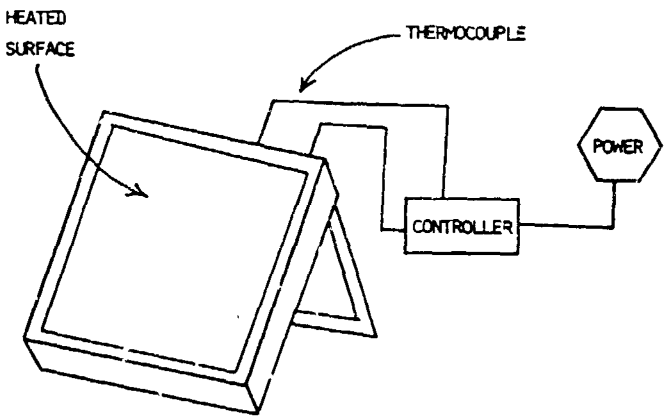
ADHESION DIAGNOSTICS:

- 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

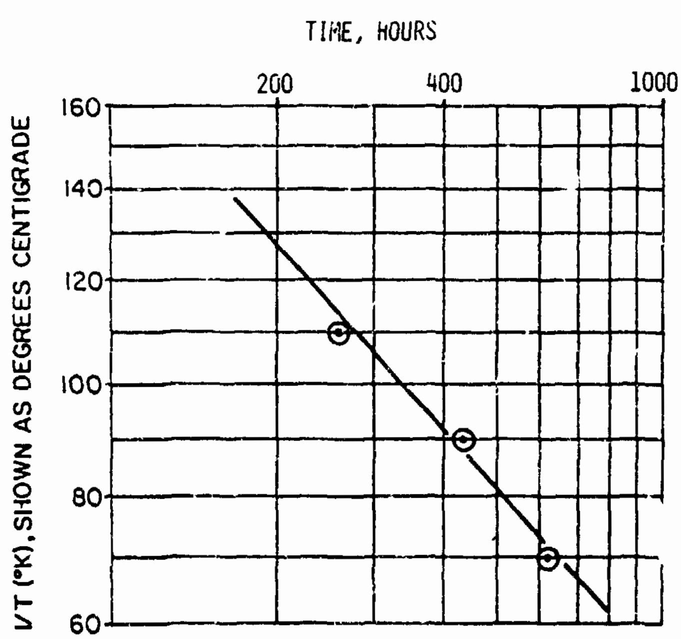
Accelerated Aging

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



- 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°
  - PREDICT SERVICE LIFE BY EXTRAPOLATION TO LOWER TEMPERATURES
  - TIME TO ONSET OF DEGRADATION (INDUCTION PERIOD)
  - PROBABILITY DISTRIBUTION-FAILURE
- EXAMPLE: POLYPROPYLENE - INDUCTION TIME



Advanced Stabilizers

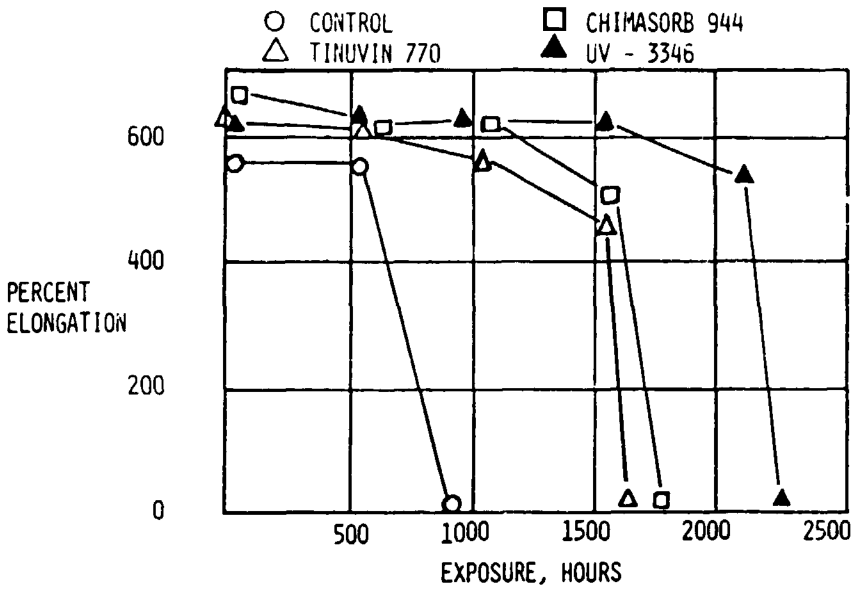
GENERAL DEGRADATION MECHANISM		STABILIZATION ADDITIVE
LIGHT (UV) ⟶		
ABSORPTION	⟶	SCREENERS
↓		
EXCITED SPECIES (ACTIVATED KETONES)	⟶	QUENCHERS
↓		
RADICALS P•, H•	⟶	FREE RADICAL SCAVENGERS
↓ + O_2		
ROOH (HYDROPEROXIDES)	⟶	HYDROPEROXIDE DECOMPOSERS
↓		
P•, RO•, HO•		

AUTOCATALYTIC 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

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



- FAILURE: LOSS OR CONSUMPTION OF CHEMISTRY? NEED FOR ANALYTICAL METHOD
- CYASORB UV-336 (CYANAMIDE) CLEARLY BETTER
- SYSTEM EVALUATION: EVA/TBEC/UV-2098/UV-3346 MODULES, ADHESION, FLAMMABILITY, ETC.

Antisoiling Treatments

SURFACE CHEMISTRY:

- HARD
- SMOOTH
- HY ROPHOBIC
- OLEOPHOBIC
- ION FREE
- LOW SURFACE ENERGY

SURFACE INVESTIGATED:

- SUNADEX GLASS
- TEDLAR (100 BG 30 UT)
- ACRYLAR (ACRYLIC FILM)

TREATMENTS REMAINING:

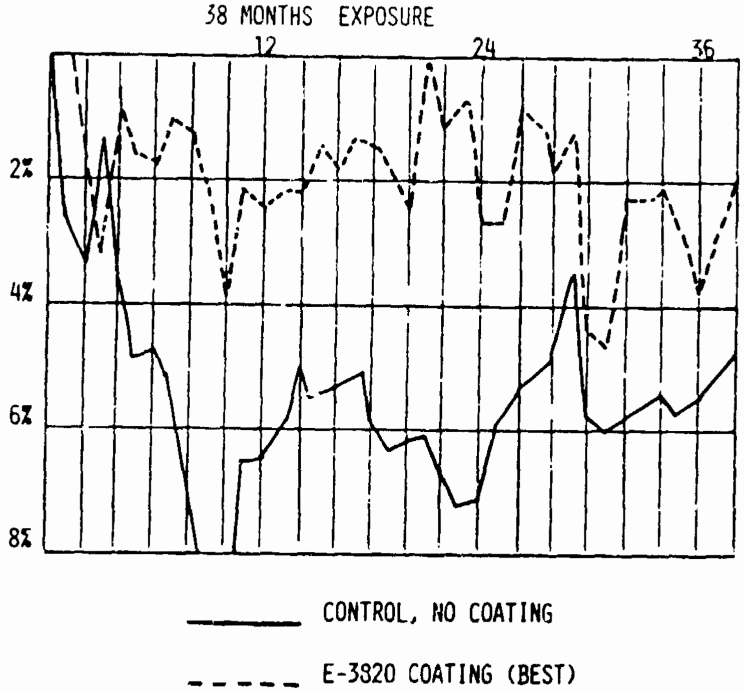
- L-1668 FLUOROSILANE (3M)
- E-3820 PERFLUORODECANOIC ACID/ SILANE (DOW CORNING)
- STILL EFFECTIVE AT 38 MONTHS OUTDOOR EXPOSURE
- RESULTS IN IMPROVED POWER OUTPUT
- FLUOROALKYL SILANE CHEMISTRY APPEARS TO BE MOST EFFECTIVE

Soiling Experiments

THIRTY-TWO MONTHS EXPOSURE
ENFIELD, CONNECTICUT

% LOSS IN I_{SC} WITH STANDARD CELL TREATED
TEDLAR 100BG300UT

(SUPPORT ON GLASS)

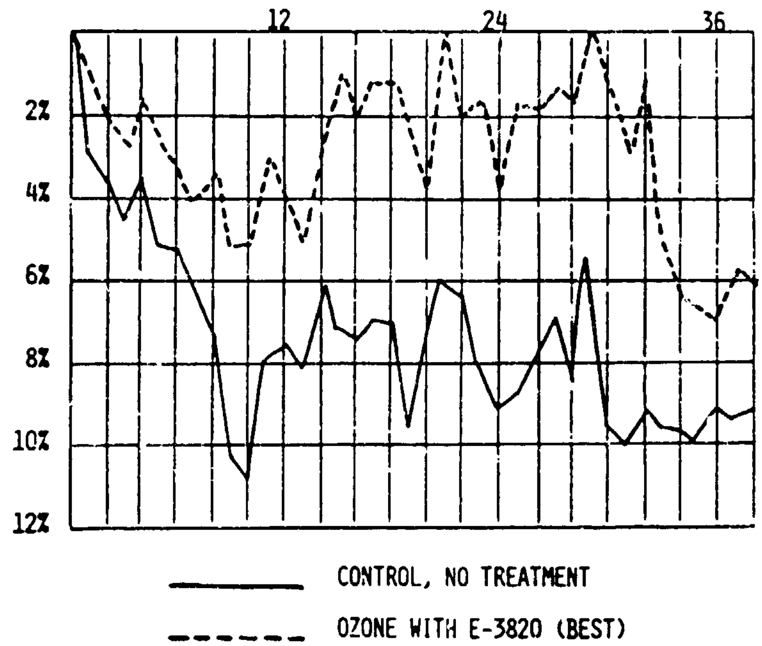


ESTIMATED AVERAGE POWER IMPROVEMENT, 3.8%

THIRTY-TWO MONTHS EXPOSURE
ENFIELD, CONNECTICUT

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

38 MONTHS EXPOSURE

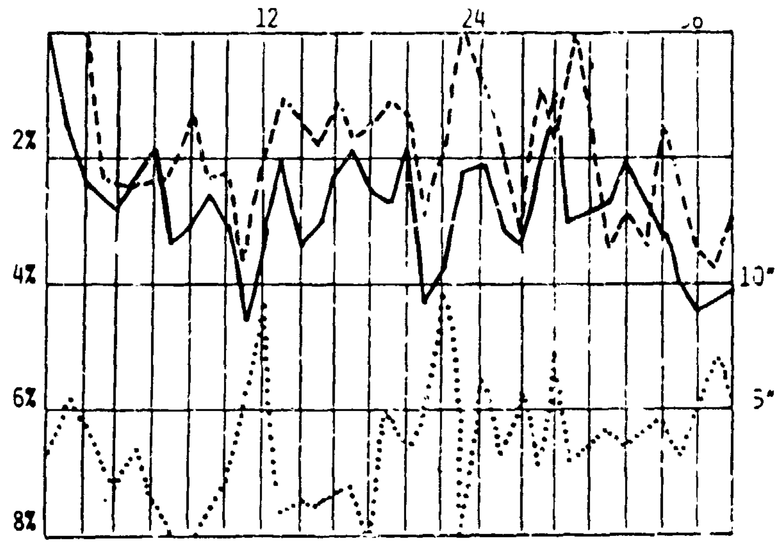


ESTIMATED AVERAGE POWER IMPROVEMENT, 3.9%

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

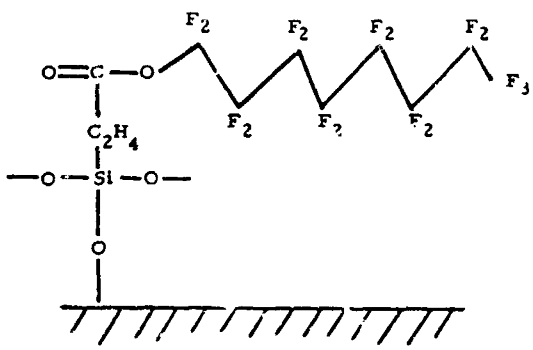
- STILL EFFECTIVE AFTER THREE YEARS OUTDOOR EXPOSURE
- PERMANENCE APPEARS TO BE GOOD
- POSSIBILITY FOR IMPROVED PERFORMANCE BY INCREASING SOIL REPLELLANCY

NEW CANDIATE(S):

- LOWEST SURFACE ENERGY EVER REPORTED: POLYMER OF PERFLUORO-OCTYL METHACRYLATE

  γ_c = 10.6 DYNE CM^{-1}

- REACT WITH TRIMETHOXY HYDROGEN SILANE TO FORM ADDUCT WITH GLASS-REACTIVE GROUP
- EVALUATE IN SOILING TESTS



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 ?

FILM	REF. INDEX	% T	COST $/FT^2/MIL
TEFZEL	1.403	85.6	0.128
KAYNAR	1.420	88.8	0.055
HALAR	1.40	85.3	0.096
PFA	1.30	88.4	0.123
FEP	1.34	93.6	0.109

- 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
  - POSSIBLITY 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