N86-29359

ENCAPSULATION MATERIALS RESEARCH

SPRINGBORN LABORATORIES

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
- ADHESIVE BOND DURABILITY
- FLAMMABILITY
- ELECTRICAL ISOLATION

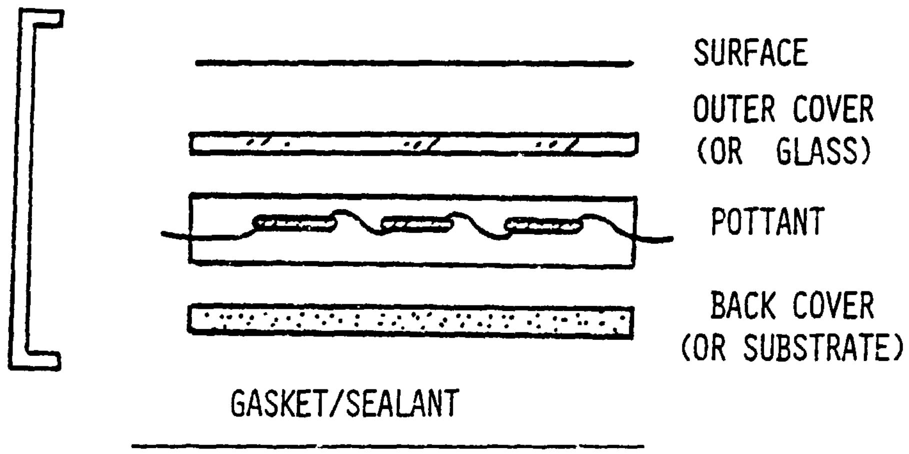
Phase III

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

- FLAMMABILITY
- ADHESIVE BOND DURABILITY
- ELECTRICAL INTEGRITY
- ENVIRONMENTAL DEGRADATION
- WHAT ARE DOMINANT FAILURE MODES ?
- WHERE IS STABILIZATION NEEDED ?

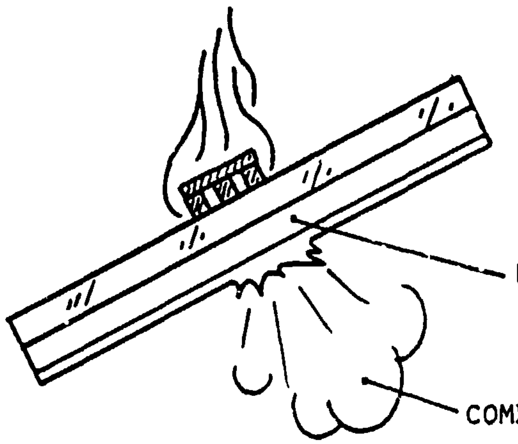
Module Flammability

PROBLEM:

- BURNING MODULES CAN SERVE AS IGNITION SOURCE FOR OTHER STRUCTURES
- 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 WITH KAPTON BACK COVERS (HIGH STRENGTH) PASS TEST DUE TO ABILITY TO RETAIN COMBUSTIBLE GASSES ("B" BRAND)
- KAPTON IS <u>VERY</u> EXPENSIVE
- INEXPENSIVE HIGH STRENGTH HIGH TEMPERATURE BACK COVER NEEDED
- SOME SUCCESS WITH COATED FIBERGLASS CLOTH (PROPRIETARY COATINGS) ("A" BRAND)

GOAL:

- PREVENT SPREAD OF FLAME
- PASS UL-790

APPROACHES:

(1) HIGH STRENGTH HEAT RESISTANT BACK COVERS

- CERAMIC PAPER
- POLYMER FILM LAMINATES WITH GLASS CLOTH INTERLAYER
- 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
(MOST LIKELY)

EVALUATION OF CANDIDATE MATERIALS

CONVENTIONAL TESTS:

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

SPECIAL TEST METHOD:

- HIGH TEMPERATURE BURST CELL
- 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

DATA:

	BURST STRENGTH, PSI			
	300 °F	400 °F	500 °F	600 °F
TEDLAR 200BS30WH	~5	<<5	0	0
KAPTON (4 MIL)	>50	40	30	20
GLASS CLOTH (PROPRIETARY COATING)	- - - - POROUS - - - -			

- MOST EFFECTIVE BACK COVER IS POROUS !
- RELEASED GASSES DILUTED BELOW LOWER EXPLOSION LIMIT ? ?

FIRE RETARDANT ADDITIVES:

- GOAL: FIRE RETARDANT EVA

FORMULATION:	PARTS	PERCENT
ELVAX 150	100	49
TBEC PEROXIDE	1.5	0.7
ANTIMONY OXIDE	7.0	3.4
DECARBROMODIPHENYL OXIDE	20.0	9.8
ALUMINUM TRIHYDRATE	75.0	36.8

EVALUATION:

- UL-94 VERTICAL BURN V-0 (SELF EXTINGUISHING)
  - COMPRESSION MOLDED WITH "CRANEGLAS" CLOTH:
- ASTM D-23863 LIMITING OXYGEN INDEX 30% (GOOD)

FOR COMPARISON:

MATERIAL	OXYGEN INDEX
PARAFFIN	16
EVA (ELVAX 150)	18
SILICONE RUBBER	30
PVC	~ 50
TEFLON (FEP)	~ 93

CONCLUSIONS:

- FIRE RETARDANCY INCREASES WITH AMOUNT OF ALUMINUM TRIHYDRATE
- 4:1 BROMINE: ANTIMONY RATIO APPEARS TO BE OPTIMUM
- NON-WOVEN GLASS CLOTH PREVENTS DRIPPING - REINFORCES THE COMPOSITION
- EVA CAN BE FORMULATED TO HAVE FLAMMABILITY EQUIVALENT TO SILICONE RUBBER
- HIGHER OXYGEN INDEX VALUES POSSIBLE

Adhesion Experiments

STATUS:

- PRIMER FORMULATIONS IDENTIFIED FOR ALMOST ALL INTERFACES IN MODULES
- SELF-PRIMING FORMULATIONS OF EVA (TO GLASS, CELLS) DEVELOPED; AVAILABLE

CONTINUED PRIMER STUDIES:

- GOAL: REDUCE LIST OF PRIMERS TO "UNIVERSAL" FORMULATION(s)
- 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

DURABILITY

ADHESIVE BONDS ARE RESPONSIBLE FOR MECHANICAL INTEGRITY OF ENTIRE MODULE - WHAT IS THEIR LIFETIME ?

- HOW DURABLE ARE ADHESIVE BONDS ?
- UNDER WHAT CONDITIONS ?
- REVERSIBILITY AND RECOVERY ?
- MODELLING AND PREDICTION ?
- TEST METHODS ?

ADHESION DIAGNOSTICS:

- PROGRAM STARTED WITH CASE WESTERN RESERVE UNIVERSITY - JACK KOENIG

C-3

Adhesion Diagnostics

TEST SPECIMENS:

- EVA COMPOUNDED WITH HIGH LOADINGS OF SILANE TREATED GLASS BEADS - RESEMBLES GLASS REINFORCED POLYMER
- GLASS: SPHERICAL "A" - GLASS BEADS, MEAN DIAMETER 20 μ , 2% BY WEIGHT SILANE PRIMER
- SPECIMENS AT CASE WESTERN FOR "DRIFT" ANALYSIS (SPECTROSCOPY)
- SPECIMENS AT SPRINGBORN FOR MECHANICAL ANALYSIS

GOALS:

- CORRELATE SPECTROSCOPIC OBSERVATIONS WITH MECHANICAL PERFORMANCE
- DETERMINE DEGRADATION RATES (KINETICS)
- ASSESS SERVICE LIFE

AGING CONDITIONS:

- HYDROLYSIS CONSIDERED TO BE DOMINANT FAILURE MECHANISM
- WATER IMMERSION:

  TEMPERATURES: 40^{o}, 60^{o}, 80^{o}

  TIMES: 100, 250, 500, 1000, 2000 HRS.
- TESTING: MECHANICAL, SPECTROSCOPIC

- LARGEST MEASURABLE CHANGE: WEIGHT GAIN
  (WATER ABSORPTION)

PERCENT WEIGHT GAIN

TEMPERATURE	40° C	60° C	80°C
EVA/GLASS NO PRIMER	51 % 2,000 HR	2015 % 2,000 HR	500 % 500 HR
EVA/GLASS WITH PRIMER	3.5 % 2,000 HR	35 % 2,000 HR	62 % 1,000 HR
EVA, CONTROL	0.3 % 2,000 HR	0.4 % 2,000 HR	1.0 % 2,000 HR

* NO SPECIMENS SURVIVING THIS POINT

- WEIGHT GAIN ASSUMED TO BE WATER ABSORPTION AT POLYMER/GLASS INTERFACE (ALSO OBSERVED BY SPECTROSCOPY)
- PRIMER HAS SIGNIFICANT EFFECT ON ABSORPTION
- MECHANICAL PROPERTIES: LITTLE CHANGE UP TO 50 % WEIGHT GAIN-ELONGATION BEGINS TO DECREASE
- ALMOST NO CHANGE IN POLYETHYLENE/GLASS BEAD SPECIMENS

REVERSIBILITY:

- DRIED AT 105°C/72 HRS - LIMIT OF REVERSIBILITY

	40°	60°	80°
NO PRIMER	ALL	500 HRS	250 HRS
WITH PRIMER	ALL	ALL	1,000 HRS

- WATER ABSORPTION - LARGEST PROPERTY CHANGE
- PRIMER STABILIZERS GLASS/POLYMER INTERFACE
- HYDROTHERMAL " DAMAGE " TO BONDS AT THE INTERFACE IS REVERSIBLE UP TO A LIMIT
- EQUILIBRIUM WATER ABSORPTION VALUES MAY PROVIDE NEW METHOD OF EVALUATING ADHESIVE BONDS - RECOVERY PROPERTIES

LIFETIME:

- DOES POLYMER GAIN WATER TO POINT OF NON-REVERSIBILITY, OR IS IT " INDUCTION PERIOD " TYPE ?
- NEED MORE DATA POINTS FOR MODELING

Electrical Isolation

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

METHOD:

- HV-DC POWER SUPPLY, SYMMETRIC ELECTRODES
- SPECIFIED RATE OF RISE (500 V/SEC)
- PLOT AVERAGE BREAKDOWN VOLTAGE, V_A VS THICKNESS
- STRAIGHT LINE RELATIONSHIP: SLOPE EQUALS "INTRINSIC DIELECTRIC STRENGTH" (DC)
- MEASUREMENTS TO DATE:
  EVA 9918, $dV/dT = 3.65$ KV/MIL

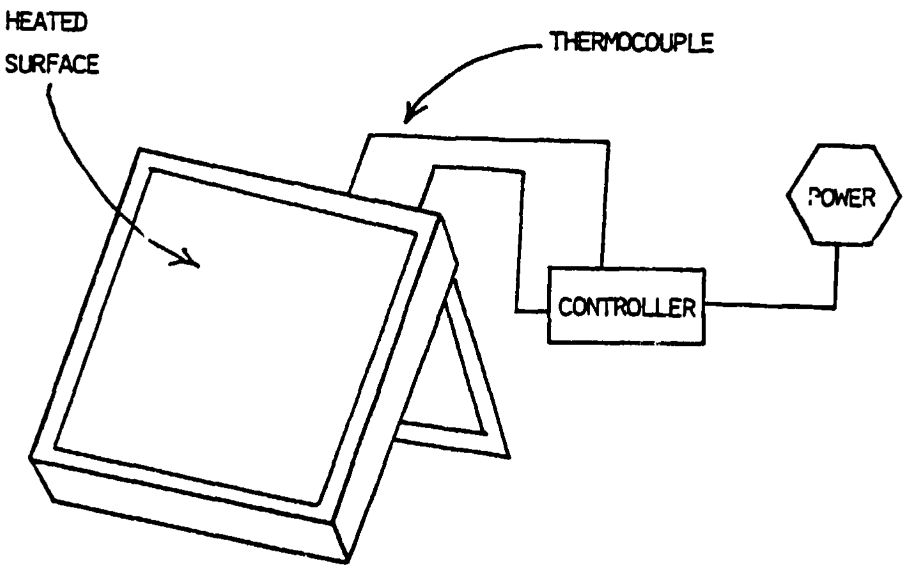
GOALS:

- REMEASURE dV/dT:
  - THERMAL AGING
  - WATER ABSORPTION
  - ENVIRONMENTAL EXPOSURE
  - FIELD STRESS AGING
- RECALCULATE THE REQUIRED INSULATION THICKNESS FOR SERVICE LIFE OF THE MODULE

Accelerated Aging Test Program

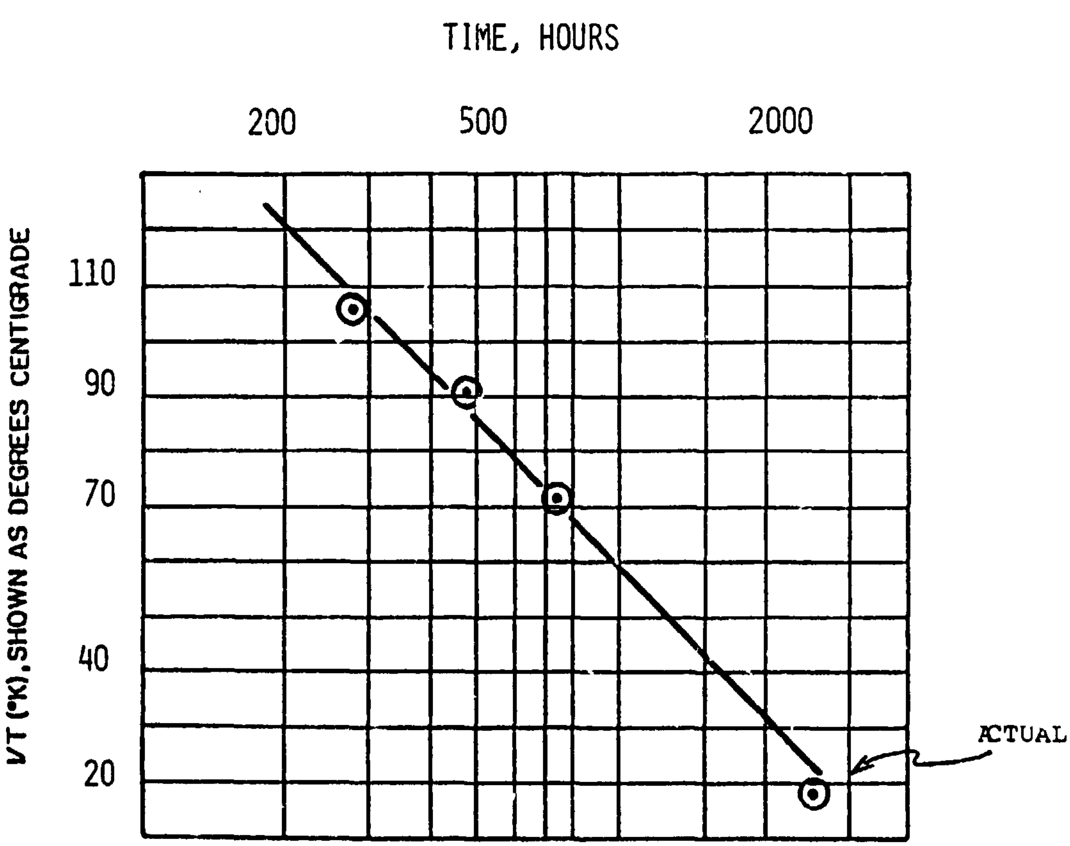
OUTDOOR PHOTOTHERMAL AGING REACTORS
(OPTAR)

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



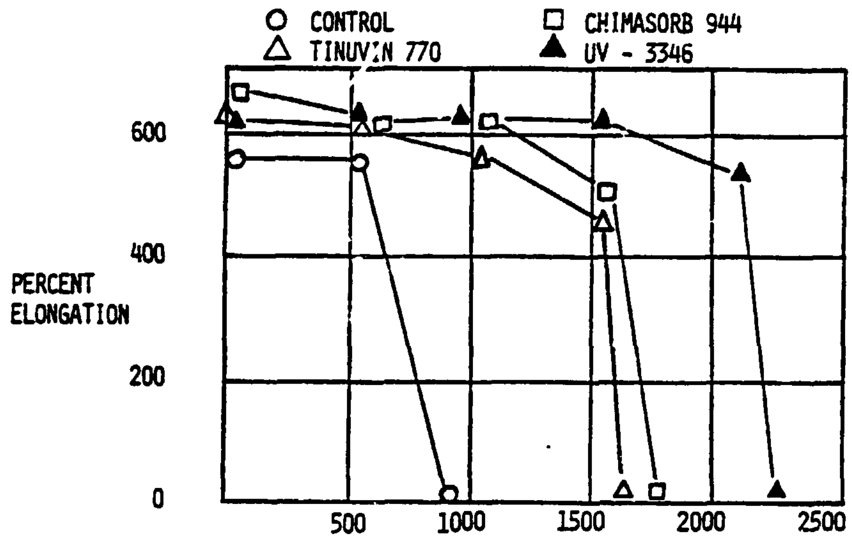
Accelerated Aging

- USEFUL FOR EVALUATING CANDIDATE FORMULATIONS - COMPARISON
- EVALUATED WHOLE MODULES
- DETERMINE UPPER LEVEL SERVICE TEMPERATURES
- MODELLING:
  - TIME TO ONSET OF DEGRADATION (INDUCTION PERIOD, t_i)
    EXAMPLE: POLYPROYLENE
  - ARRHENIUS: LOG, t_i vs. $1/K^0$
  - PREDICT SERICE LIFE BY EXTRAPOLATION TO LOWER TEMPERATURES



Accelerated Aging (OPTAR)

- INDUCTION PERIOD MEASUREMENT - USEFUL FOR STABILIZER SELECTION
- EXAMPLE: HALS TYPE STABILIZERS



- ADVANCE EVA FORMULATION (NO. 18170) LUPERSOL TBEC, UV-2098 (CYANAMIDE, UV-SCREEN) UV-3346 (CYANAMIDE, HALS)
- MASSIVE TEST PROGRAM STARTED: MODULES, OUTER COVERS, ADHESION TEST SPECIMENS, POTTANT FORMULATIONS, ETC.
- RADIOMETER INSTALLED ON OPTAR DEVICES - POSSIBILITY FOR MODELING BASED ON HEAT PLUS LIGHT ? ? ?

Anti-Soiling Treatments

SURFACE CHEMISTRY:

- HARD
- SMOOTH
- HYDROPHOBIC
- 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 46 MONTHS OUTDOOR EXPOSURE
- RESULTS IN IMPROVED POWER OUTPUT
- FLUOROALKYL SILANE CHEMISTRY APPEARS TO BE MOST EFFECTIVE

NEW TREATMENTS :

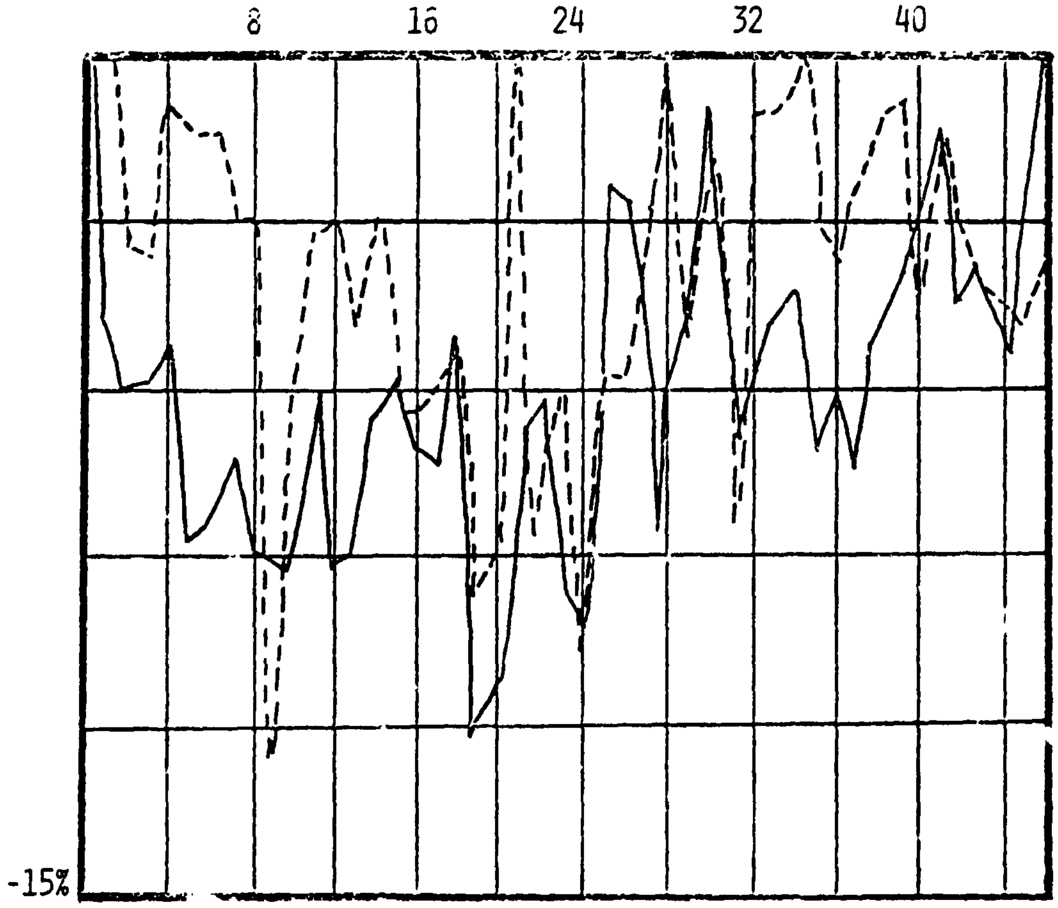
- TWO NEW CANDIDATES FROM DOW CORNING - JUST STARTED

Soiling Experiments

FORTY SIX MONTHS EXPOSURE
ENFIELD, CONNECTICUT

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

46 MONTHS EXPOSURE



——————— CONTROL, NO TREATMENT

- - - - - - - L1668 (3M)

• ESTIMATED AVERAGE POWER IMPROVEMENT, 1%

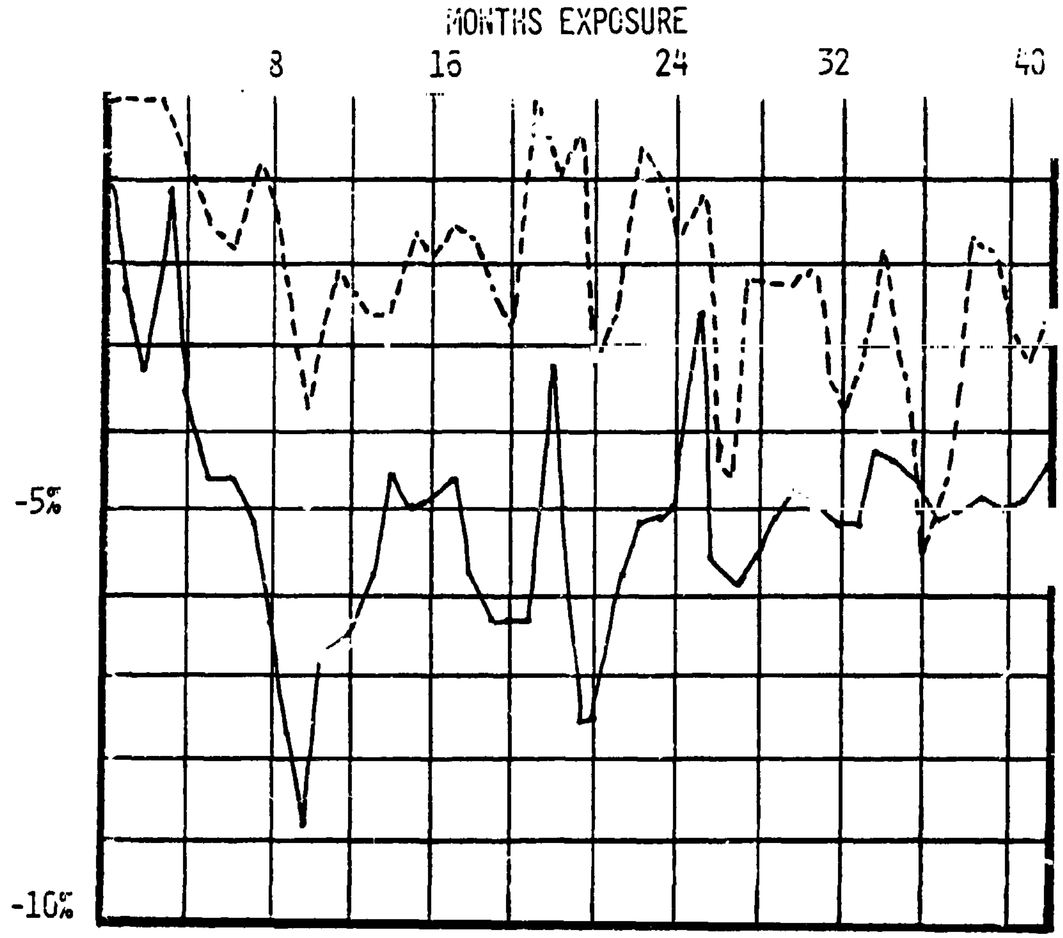
FORTY SIX MONTHS EXPOSURE

ENFIELD, CONNECTICUT

% LOSS IN I_{SC} WITH STANDARD CELL TREATED

TEDLAR 100BG300UT

(SUPPORT ON GLASS)



——————— CONTROL, NO TREATMENT

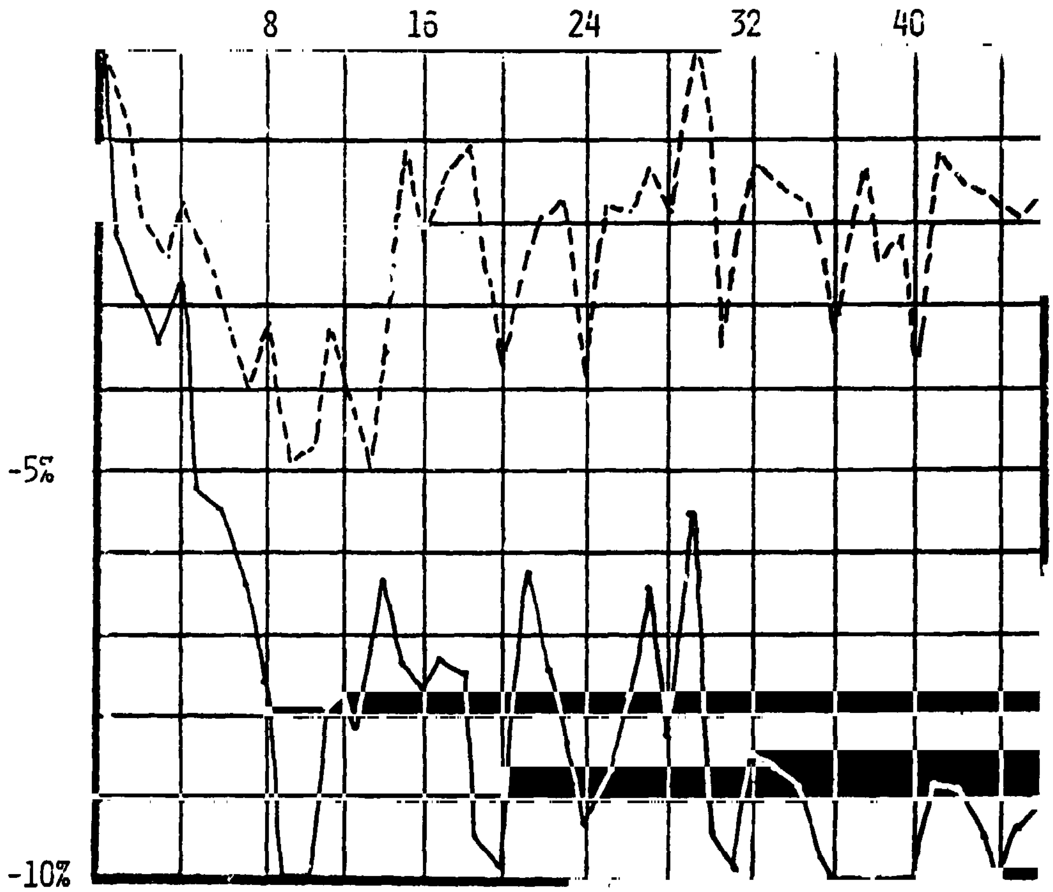
- - - - - - - E3820

• ESTIMATED AVERAGE POWER IMPROVEMENT, 3.8%

FORTY SIX MONTHS EXPOSURE
ENFIELD, CONNECTICUT

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

45 MONTHS EXPOSURE



CONTROL, NO TREATMENT

OZONE + E3820

● ESTIMATED AVERAGE POWER IMPROVEMENT, 3.9%

Outer Covers

(SUBSTRATE DESIGN)

- RECENT INDUSTRIAL INTEREST - BOTH CRYSTAL AND THIN FILM AMORPHOUS APPLICATIONS
- NEW CONCEPT: POTTANTS ARE VERY STABLE - NO FURTHER NEED FOR UV SCREENING IN OUTER COVER (?)
- NON-SCREENING FILM REQUIREMENTS: TRANSPARENT, LOW SHRINKAGE, WEATHERABLE, BONDABLE
- BEST CANDIDATES: FLUOROPOLYMERS

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
.FA	1.30	88.4	0.123
FEP	1.34	93.6	0.109
FLUOREX	1.46	90.0	0.17

- FEP MAY BE GOOD CHOICE:
  - HIGH TRANSPARENCY
  - OUTSTANDING WEATHERABILITY
  - MAY IMPROVE OPTICAL THROUGHPUT BY 2% DUE TO OPTICAL COUPLING
  - REQUIRES BONDING TECHNOLOGY: SURFACE TREATMENT NOT UV STABLE (DU PONT)
  - UNDER EVALUATION IN MODULE FABRICATION AND OUTDOOR EXPOSURE EXPERIMENTS

Thin-Film/Amorphous Photovoltaics

CANDIDATE POLYMERS:

- PROCESSABLE <100° C
- OPTICALLY TRANSPARENT (BEFORE OR AFTER CURING)
- CURABLE: NO THERMAL CREEP
- EXTRUSION: THIN FILMS DESIRABLE
- WEATHERABLE OR UNGRADABLE
- FLEXIBLE

MATERIAL CLASS	MANUFACTURER	$/LB
POLYETHYLENE (LDPE)	MANY	.50 - .60
ETHYLENE/VINYL ACETATE	DU PONT, USI	.60 - .80
ETHYLENE/ACRYLIC	DOW, GULF	.80 - 1.00
IONOMER	DU PONT	1.08 - 1.60
ALIPHATIC URETHANE	UPJOHN	1.70 - 2.50
HOT MELT ADHESIVES (HYDROCARBON, POLYAMIDE POLYETHER, ACRYLIC)	MANY	80 - 2.50

ENCAPSULATION METHOD:

- EXTRUSION COATING
- FILM LAMINATION: EXTRUDE THE POTTANT ON AN OUTER COVER FILM AS A CARRIER, USE COMBINATION FOR LAMINATION.

CURE METHOD:

- MOISTURE CURE (MODIFIED CHEMISTRY)
- PEROXIDE DECOMPOSITION (HEAT)
- UV CURE (PHOTOINITIATION)
- ELECTRON BEAM (?) MAY BE POSSIBLE WITH AMORPHOUS SILICON

Conclusions

FLAMMABILITY:

- BACK COVERS - - FUNCTION ?
- SELF EXTINGUISHING FIRE RETARDANT EVA DEVELOPED

ADHESION:

- NEW TEST METHOD FOR PRIMER EVALUATION AND BOND DURABILITY
- CAN DEMONSTRATE BOND RECOVERY & LIMIT OF REVERSIBILITY

ELECTRICAL ISOLATION:

- INTRINSIC DIELECTRIC TEST METHOD DEVELOPED

ACCELERATED AGING:

- " OPTAR " METHOD BEST AGING TECHNIQUE DISCOVERED SO ARE
- MODELING/LIFE PREDICTION ENCOURAGING
  - 70^{o} & 90^{o} C VERY GOOD CONDITION
  - COPPER REACTIONS NOT AS SEVERE AS ANTICIPATED - EXCEPT AT 105^{o} C
  - LUPERSOL - TBEC CURED FORMULATIONS APPEAR MORE STABLE
- BEST STABILIZERS: UV-2098 SCREENER, UV-3346 HALS TYPE (BOTH CYANAMIDE)

SOILING:

- TREATMENTS STILL EFFECTIVE AFTER 46 MONTHS
- MOST EFFECTIVE ON ORGANIC FILMS

THIN-FILM PV:

- ENCAPSULANT INVESTIGATIONS BEGUN

Future Work

- FLAMMABILITY:
  - ENHANCED FIRE RETAR DANT FORMULATIONS
  - SMALL SCALE MODULE "BURNS "
- ADHESION:
  - MORE WORK ON " UNIVERSAL " PRIMERS
  - MORE DEVELOPMENT OF DIAGNOSTIC TEST METHOD
  - AGING OF ADHESION TEST SPECIMENS
- ELECTRICAL INTEGRITY: DIELECTRIC STRENGTH VERSUS AGING OF ENCAPSULATION MATERIALS:
  - ACCELERATED AGING
    MASSIVE NUMBER OF TEST SPECIMENS BEING DEVELOPED - MODULES, OUTER COVERS
    ADVANCED STABILIZER SYSTEMS
  - NON-SCREENING WEATHERABLE OUTER COVERS
    EMPHASIS ON BONDING
  - THIN-FILM PV: DEVELOPMENT WORK AND MATERIALS RECOMMENDATIONS