N87-16401

JPL ENCAPSULATION TASK

SPRINGBORN LABORATORIES, INC.

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JPL Encapsulation Task (Inception: 1975)

OVERALL GOAL:
- PRODUCTION OF ELECTRICAL POWER FROM PHOTOVOLTAICS COMPETITIVE WITH COMMERCIAL POWER SOURCES
- TARGET: $0.70 PER PEAK WATT (1980 DOLLARS)

WHY ENCAPSULATION?

- MECHANICAL SUPPORT — PREVENT CELL BREAKAGE
- THERMAL CONDUCTION — DISSIPATE HEAT
- ENVIRONMENTAL PROTECTION — PREVENT CORROSION
- PACKAGING / HANDLING — TRANSPORTATION AND FIELD DEPLOYMENT OF MODULES

Performance Requirements

• SERVICE LIFE	30 YEARS
• LIGHT TRANSMISSION TO SOLAR CELLS	>90% OF INCIDENT
• LOSS IN MODULE POWER AFTER 30 YEARS	<10% OF INITIAL
• PROCESSING AND FABRICATION	AUTOMATED
• STRUCTURAL PERFORMANCE (INCLUDING HANDLING AND WEATHERING)	NO FAILURES

- MUST CONFORM TO COST GOALS

Encapsulation Cost Goals

- $ 0.70/W_{PK} x 10 W/FT^2 = $7.00 / FT^2

ALLOWABLE TOTAL MODULE COST

SOLAR CELLS, COST
$5.60 / FT^2

ENCAPSULATION COST:
(RAW MATERIALS ONLY)
$1.40 / FT^2

	% OF MODULE COST	$/M^2	$/FT^2
ENCAPSULATION SYSTEM	20	14	1.40*

* 1980 $

- COST NOW SERVED AS DRIVER FOR SELECTION OF MATERIALS
- NEED TO REDEFINE ENCAPSULATION REQUIREMENTS
  - WHAT COMPONENTS ARE NEEDED ?
  - WHAT MUST MATERIALS DO ?
- DOES ENCAPSULATION PACKAGE MEET BOTH COST AND PERFORMANCE REQUIREMENTS ?

Early Encapsulation Systems

TWO SCHOOLS OF THOUGHT:

A. POURABLE SYRUPS

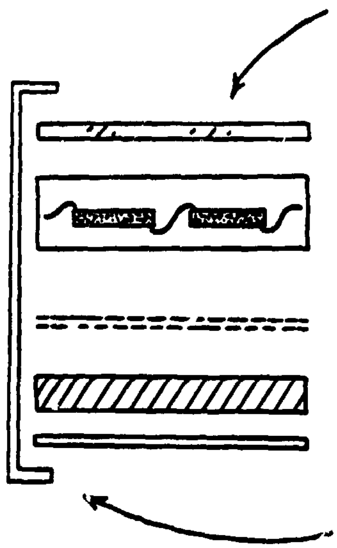
B. DRY FILM LAMINATION

APPROACHES

COMPONENTS	DEFICIENCES
• SILICONE LIQUIDS VERY HIGH COST ($12 / LB) (CASTING SYRUP) • URETHANE LIQUIDS (CASTING SYRUP)	MIXING AND PUMPING UNPREDICTABLE ADHESION LONG CURE TIMES BUBBLE ENTRAPMENT MOISTURE SENSITIVE YELLOWING WITH AGE
• POLYVINYL BUTYRAL (PVB) (LAMINATION FILM)	SPECIALIZED STORAGE DIFFICULT PROCESS - AUTOCLAVE LONG LAMINATION TIMES MODERATE COST
• SUBSTRATES: FIBERGLASS, ALUMINUM	HIGH THERMAL EXPANSIONS HIGH MOISTURE EXPANSION HIGH COST
• INDUSTRIAL PROCESSING	NOT CONSIDERED AT THIS TIME

- OVERALL PERFORMANCE QUESTIONABLE ?
- MAJOR OBJECTION: CANNOT MEET FSA COST GOALS

Module Construction Elements



DESIGNATION	FUNCTION
SURFACE (1) MATERIAL (2) TREATMENT	• LOW SOILING • EASY CLEANING • ANTIREFLECTIVE • ABRASION RESISTANT
FRONT COVER	• UV SCREENING • STRUCTURAL
POTTANT	• PRIMARY CELL PROTECTION • OPTICAL COUPLING
POROUS SPACER	• AIR RELEASE • MECHANICAL SEPARATION
SUBSTRATE	• STRUCTURAL
BACK COVER	• MECHANICAL PROTECTION • WEATHER BARRIER • HEAT EMITTER
GASKET & SEAL	• EDGE SEALING

- ADHESIVES AND PRIMERS WHERE REQUIRED

- NOTE: TWO DESIGNS - SUBSTRATE OR SUPERSTRATE
  ONLY ONE STRUCTURAL COMPONENT

MODULE FABRICATION TECHNIQUES

(1) SHEET LAMINATION METHOD

(2) LIQUID CASTING METHOD

- GOAL : IDENTIFY COST-EFFECTIVE MATERIALS AND PROCESSES

Pottant Development

- POTTANT IS THE HEART OF THE ENCSPSULATION PACKAGE - RECEIVED GREATEST EMPHASIS
- REQUIREMENTS:
  - OPTICAL TRANSPARENCY
  - LOW MELTING POINT
  - ELECTRICAL INSULATION
  - RUBBERY (LOW MODULUS)
  - NO CELL BREAKAGE !
  - RESISTANT TO FLOW IN SERVICE
  - SUITABLE FOR AUTOMATED PRODUCTION (HIGH VOLUME)
  - COST EFFECTIVE
- THESE PROPERTIES FOUND IN TRANSPARENT "ELASTOMERS"
- PROBLEM - LOW COST POLYMERS MAY HAVE DEFICIENCIES:
  - HEAT (OXIDATION) SENSITIVITY
  - LIGHT (ULTRAVIOLET) SENSITIVITY
  - WATER (HYDROLYSIS) SENSITIVITY
- ALL TRANSPARENT "ELASTOMERS" SURVEYED TO SELECT COMPOUND WITH DESIRED PROPERTIES AND ABILITY TO BE STABILIZED WITH ADDITIVES - IMPART ENVIRONMENTAL STABILITY

Current Candidates

	COST
A. LAMINATION FILMS:	
ETHYLENE VINYL ACETATE (EVA)	\$ 0.95/ LB
ETHYLENE METHYL ACRYLATE (EMA)	\$ 0.95/ LB
B. CASTING LIQUIDS:	
POLY N-BUTYL ACRYLATE (BA)	\$ 1.00/ LB
ALIPHATIC POLYURETHANE (PU)	\$ 3.00/ LB

Development of EVA Pottant

EVA BEST OVERALL CHOICE:
ETHYLENE VINYL ACETATE POLYMERS (EVA)

ADVANTAGES	DEFICIENCIES
MANY GRADES AVAILABLE	THERMOPLASTIC (NO CREEP RESISTANCE)
OXIDATION (HEAT) STABLE	
HYDROLYSIS (WATER) STABLE	ULTRAVIOLET SENSITIVE
WIDE RANGE OF VISCOSITY	
EASY TO PROCESS	
LOW COST	
GOOD ADHESIVE PROPERTIES	

- MODULE FABRICATION GRADE DEVELOPED DESIGNATION: EVA A9918
- CONTAINS CURING AGENTS AND STABILIZERS
- DEFICIENCIES SUCCESSFULLY CORRECTED

Properties/Benefits EVA A-9918

- NO COLD STORAGE REQUIRED
- HIGH TRANSPARENCY
- DIMENSIONAL STABILITY
- GOOD FLOW AND VOLUMETRIC FILL
- FAST CURE ($0.10 /FT^2 IN VOLUME)
- EASY LAMINATION (MODULE PROCESSING)
- EXCELLENT ENVIRONMENTAL STABILITY
- LOW COST
- PRODUCED AS ROLLS OF FILM

Other Candidate Encapsulation Materials

STRUCTURAL COMPONENTS:

SUPERSTRATE : LOAD - BEARING TOP SURFACE

- TEMPERED LOW-IRON FLOAT GLASS 1/8" THICK $0.75 /FT^2

SUBSTRATES: LOAD-BEARING UNDER SURFACE

- COLD ROLLED MILD STEEL, 28 GA. $0.26 /FT^2
- WOOD HARDBOARDS, 1/8" THICK $0.14 /FT^2

(NOTE: THESE MATERIALS REQUIRE ADDITIONAL TREATMENT FOR ENVIRONMENTAL STABILITY)

POROUS SPACER: VACUUM EVACUATION, MECHANICAL SPACING AND ELECTRICAL ISOLATION

- CRANEGLAS 230 NON-WOVEN GLASS MAT $0.02 /FT^2

OUTER COVERS: MECHANICAL PROTECTION, SOIL RESISTANT, UV SCREENING

- ACRYLAR X-22417 (3M CORP.) $0.07 /FT^2
- TEDLAR 100BG30UT (DU PONT) $0.10 /FT^2
- TEDLAR 400BG20SE (DU PONT) $0.30 /FT^2
- FEP FILM , 2 MIL THICK $0.20 /FT^2

(NON-SCREENING, OUTSTANDING WEATHERABILITY HIGH TRANSPARENCY, OPTICAL COUPLING)

* ALL PRICES ARE FOR VOLUME PRODUCTION

Other Candidate Encapsulation Materials (Cont'd)

BACK COVER FILMS: MECHANICAL PROTECTION, ELECTRICAL ISOLATION, AND HEAT REFLECTION

- TEDLAR 150BS30WH (DU PONT) $ 0.13 /FT^2
- TEDLAR 200BL20WH (DU PONT) $ 0.16 /FT^2
- SCOTCHPAR 20CP WHITE (3M) $ 0.12 /FT^2
- KORAD 63000 WHITE (XCEL CORP) $ 0.09 /FT^2

GASKETS & SEALANTS : EDGE PROTECTION

- EPDM GASKET (E-633, PAWLING RUBBER CO) *
- BUTYL TAPE (5354, 3M CORP) *

------ OTHERS ------

* VARIES WITH PERIMETER

ADHESIVES / PRIMERS:

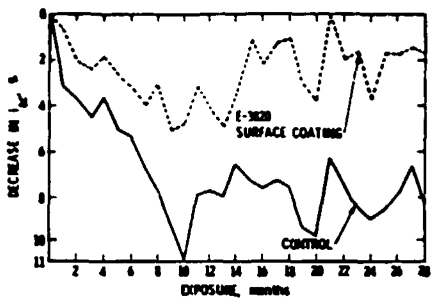
- PRIMERS IDENTIFIED FOR ALMOST ALL INTERFACES
- HIGH DURABILITY AND LOW COST (~ $0.02 /FT^2)
- SELF - PRIMING GRADE OF EVA DEVELOPED

EVA Bond Strengths, Pound/Inch of Width

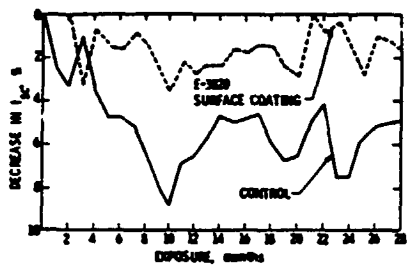
MATERIALS	CONTROL	2 WK IMMERSION	2 HR BOILING WATER
SUNADEX GLASS	34.8	30.0	32.3
WINDOW GLASS	39.6	37.9	27.1
WINDOW GLASS (SELF-PRIMING EVA)	35.4	41.9	COHESIVE

Anti-Soiling Treatments

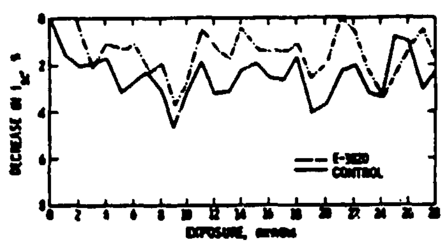
SURFACE: ACRYLAR IMPROVEMENT 3.9%



SURFACE: TEDLAR IMPROVEMENT 3.8%



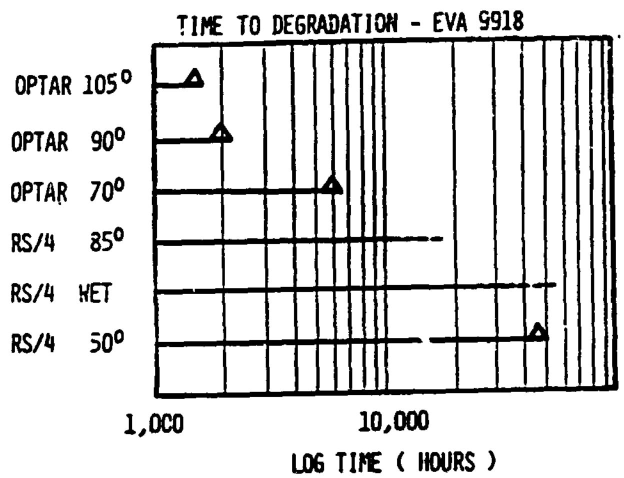
SURFACE: GLASS IMPROVEMENT 1%



Aging and Lifetime Predictions

- HOW LONG WILL MODULES LAST ?
- NEW ACCELERATED AGING TECHNIQUE DEVELOPED: OUTDOOR PHOTOTHERMAL REACTOR (OPTAR)
- COMBINES NATURAL LIGHT AND HEAT

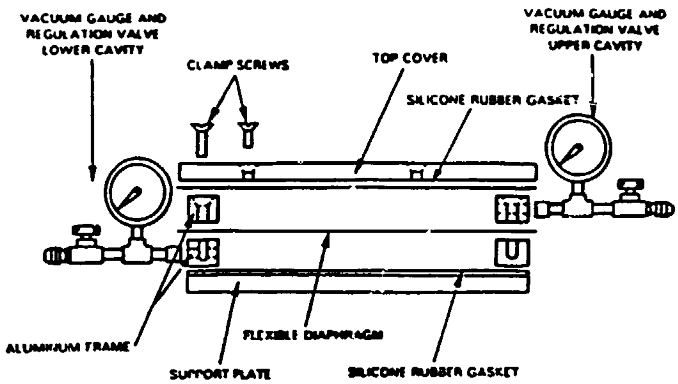
Severity Index



- OPTARS MOST EFFICIENT AGING TECHNIQUE
- MODULES HAVE VERY HIGH ENDURANCE
  NO EFFECT: 20,000 HRS - 70°C / SUNLIGHT
  LITTLE EFFECT: 20,000 HRS - 90°C / SUNLIGHT
  STRONG EFFECT: 20,000 HRS - 105°C/ SUNLIGHT
- DEGRADED MODULES SHOW NO POWER LOSS
- ENCAPSULATION SYSTEM WORKS WELL
  LIFE PROGNOSIS : GOOD !

Module Fabrication

- VACUUM LAMINATION - METHOD OF CHOICE



- RELATIVELY SIMPLE EQUIPMENT
- DRY FILMS - NO LIQUIDS
- ALL COMPONENTS ASSEMBLED IN ONE STEP
- FAST CYCLE TIMES
- AUTOMATION / HIGH VOLUME POSSIBLE
- COST EFFECTIVE

- LAMINATORS COMMERCIALLY AVAILABLE
  (SPIRE CORPORATION)

Current Status

HOW CLOSE DID WE COME ?

"TYPICAL" MODULE	VOLUME COST, $/FT^2
LOW IRON GLASS	0.75
EVA (TWO LAYERS)	0.20
POROUS SPACER	0.02
PRIMERS / ADHESIVES	0.02
BACK COVER (TEDLAR)	0.16
GASKET / SEAL (EST.)	0.15
	$ 1.30 / FT^2

- MAJOR ENCAPSULATION COMPONENTS DEVELOPED/ IDENTIFIED AND COMMERCIALLY AVAILABLE
- EVA POTTANT FILM - WIDE INDUSTRIAL ACCEPTANCE
- VIABLE MANUFACTURING PROCESS IDENTIFIED
- FIELD PERFORMANCE - VERY PROMISING

Remaining Efforts

- LIFETIME ANALYSIS : DEVELOP AND VERIFY PREDICTIVE AGING METHODS

Summary

FSA PROGRAM HAS RESULTED IN HIGH PERFORMANCE COST-EFFECTIVE ENCAPSULATION SYSTEMS FOR PHOTOVOLTAIC MODULES