November 1998 • NREL/BK-520-25850

Proceedings of the 1998 Photovoltaic Performance and Reliablity Workshop

Ben Kroposki, Editor

Doubletree Hotel
Cocoa Beach, Florida
November 3-5, 1998

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Managed by Midwest Research Institute
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under contract No. DE-AC36-83CH10093

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Preface

This workshop is designed to be a meeting where people from the general PV industry (manufacturers, users, universities, and government agencies) can discuss technical areas of module, balance-of-system, and system performance and reliability. By having a forum of presentations and discussion we can each learn from experiences in the laboratory and field.

This proceedings is the compilation of papers presented at the 11th PV Performance and Reliability Workshop held at the Double Tree Hotel in Cocoa Beach, Florida on November 3-5, 1998. The workshop was hosted by the Florida Solar Energy Center. This years workshop included presentations from 29 speakers and had one hundred and ten attendees. All of the presentations that were given are included in this proceedings.

We would like to acknowledge the organizers and chairmen of this year's workshop: Hal Post and Chris Cameron of Sandia National Labs, and Richard DeBlasio and Holly Thomas of the National Renewable Energy Laboratory. We would also like to thank David Block, Jerry Ventre, Nancy Grossman, Elena Everett, Noreen Grandbouche, Penny Hall, Shelli Keisling, Kelly Slattery, and Diane Wood from the Florida Solar Energy Center for hosting the workshop and making it so enjoyable. Special thanks to Connie Brooks of Sandia National Labs who helped compile the proceedings.

Ben Kroposki, NREL
Workshop Co-Chair

Mike Thomas, SNL
Workshop Co-Chair

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Module Reliability Testing

November 3, 1998

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1998 PHOTOVOLTATIC PERFORMANCE AND RELIABILITY WORKSHOP

Performance of Modules Made With New Encapsulants After Two Years in Arizona

R. Yorgensen

November 3, 1998

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MAJOR POINTS

- Background
- Pertinent Conclusions From PVMaT 3A
- Site Selection For Field Exposure
- Effect of 2-Axis Tracking
- The Test Matrix (Formulations and Module Types)
- Module Qualification Testing (....*counting chickens*)
- In-Situ Electrical Test Results - Modules on the Tracker
- Effect of Qual Tests on Adhesion
- Conclusions as of November 1998

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BACKGROUND

- **1989 - EVA discoloration noticed in the field**
- **1990 - STR begins study of discoloration claims**
- **1992 - STR awarded $1.5 M (30% shared) PVMaT 3A contract**
  - **Identify causes and mechanisms of discoloration**
  - **Develop non-discoloring encapsulants**
- **These goals were met 1993-1997**
- **Full-scale field testing continues**

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PERTINENT CONCLUSIONS FROM PVMaT 3A

(ZAG-3-11219-02)

- Combined high insolation and high module operating temperature drive discoloration.
- Discoloration occurs via chemical reaction of the additives and stabilizers. EVA itself is inherently resistant to discoloration.
- Discoloration of type 15295P (fast-cure) was not evident in our field survey as of 1993.
- Glass containing cerium dioxode screens UV below 320-330 nm and thereby dramatically retards the discoloration of EVA encapsulants.
- Discoloration can be photo-oxidatively bleached where oxygen-permeable backing films are used (but not between the glass and cell).
- Four new encapsulants have been developed which offer:
    - Exceptional photothermal stability
    - Lamination process same as existing formulas
    - Low cost

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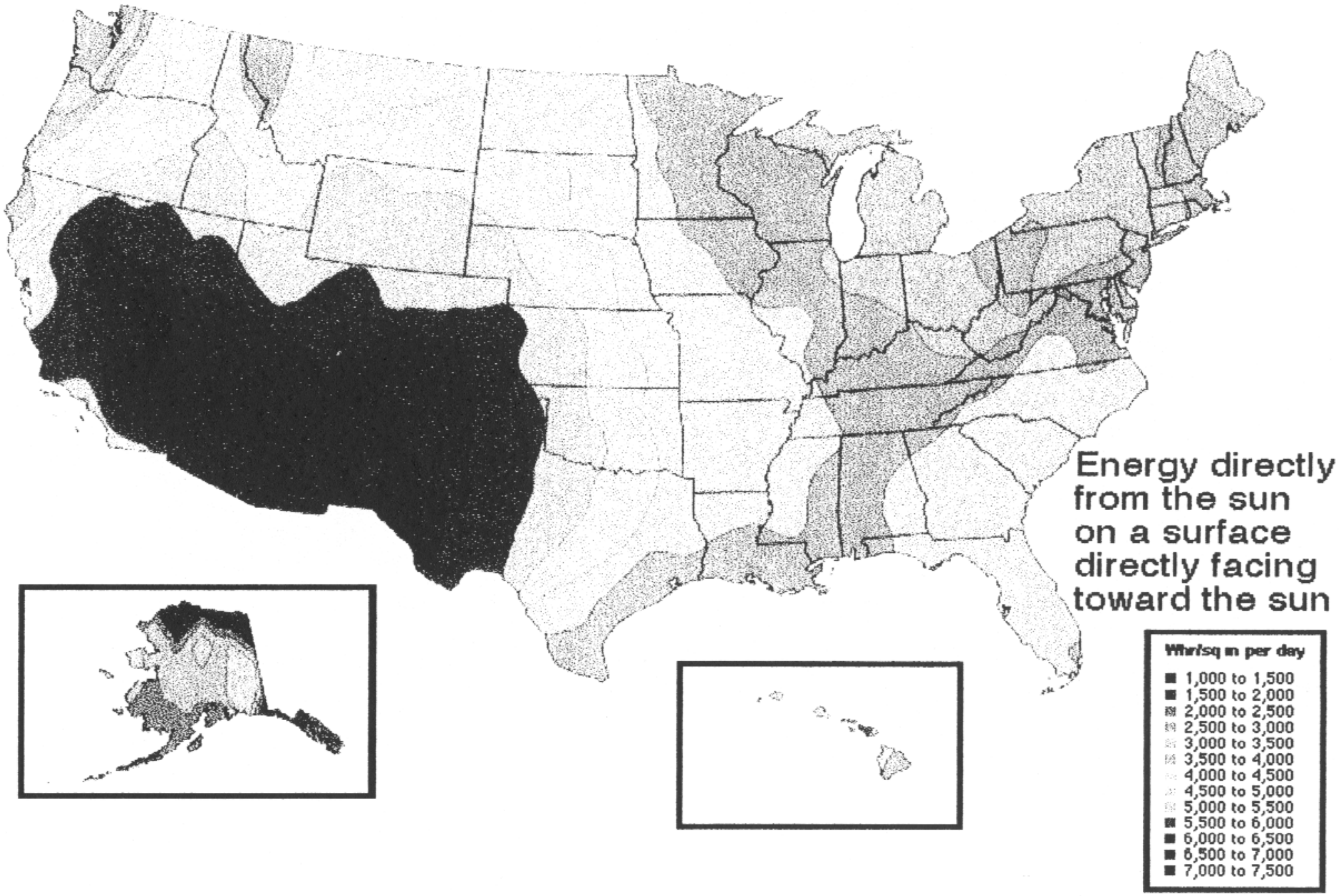
Average Daily Solar Radiation 1961-1990



Source: Ohio State University, Steen

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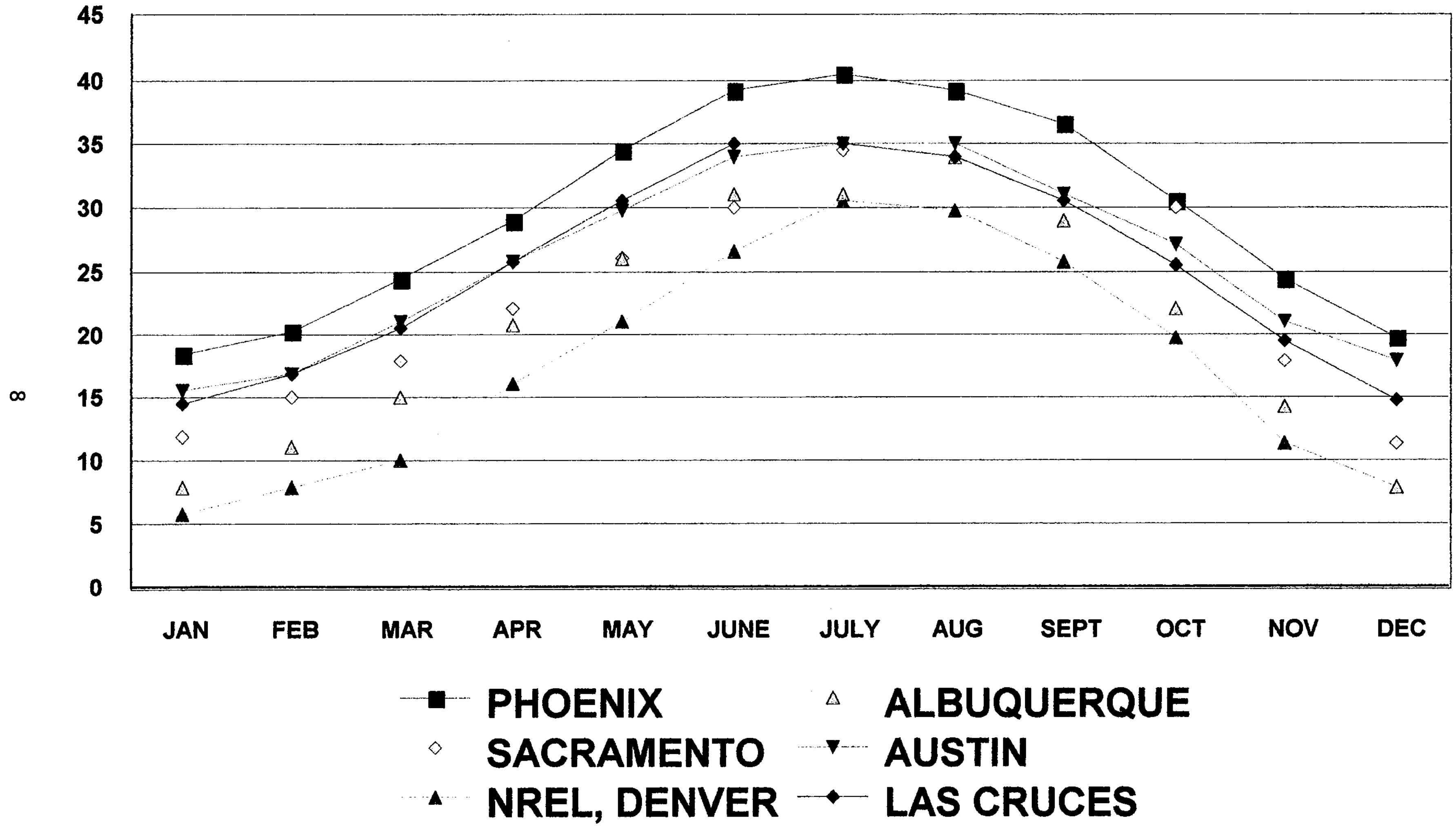
The Maximum Daily Ambient Temperature
At Each Photovoltaic Test Facility



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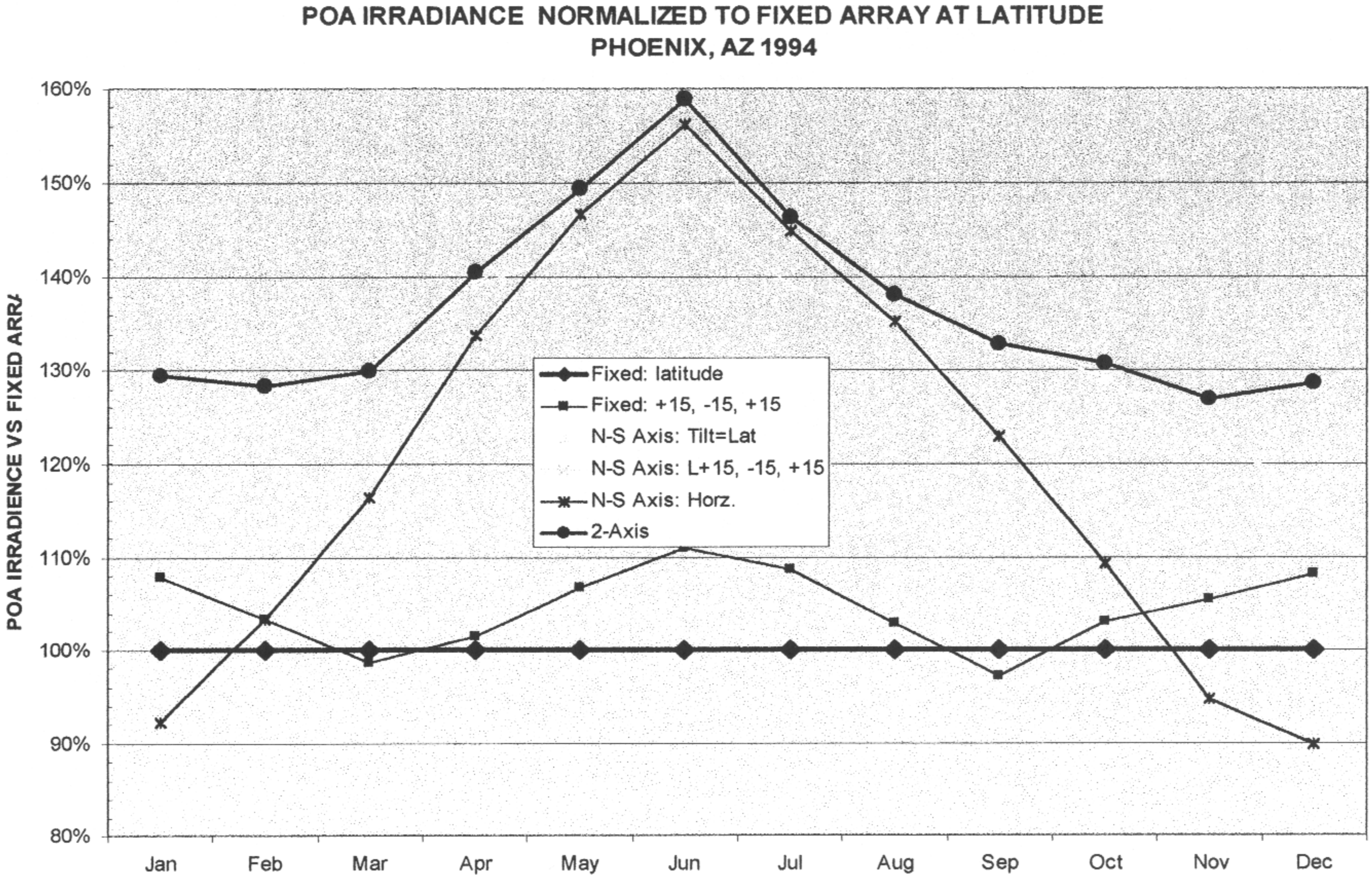

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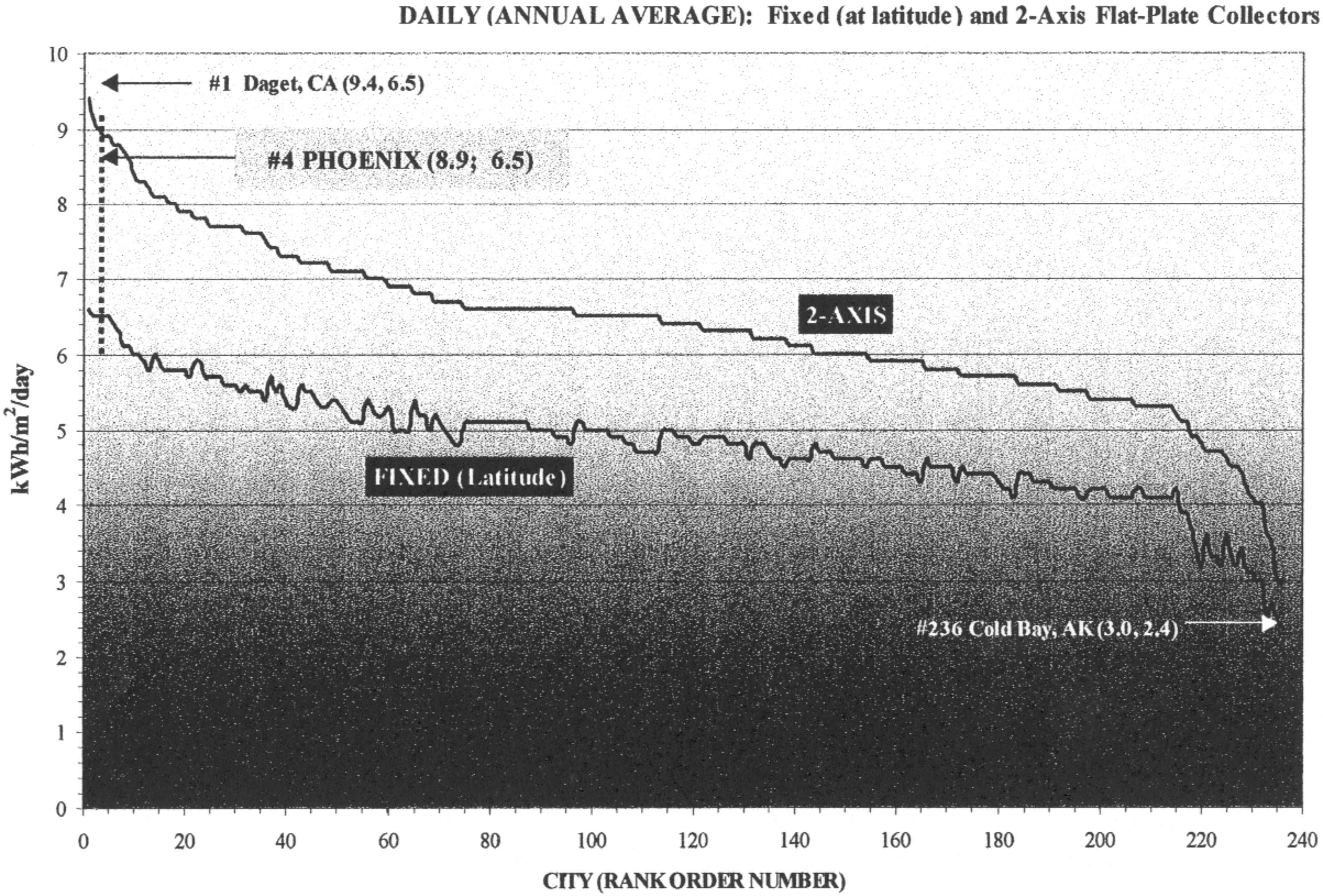
SOLAR RADIATION: US CITIES



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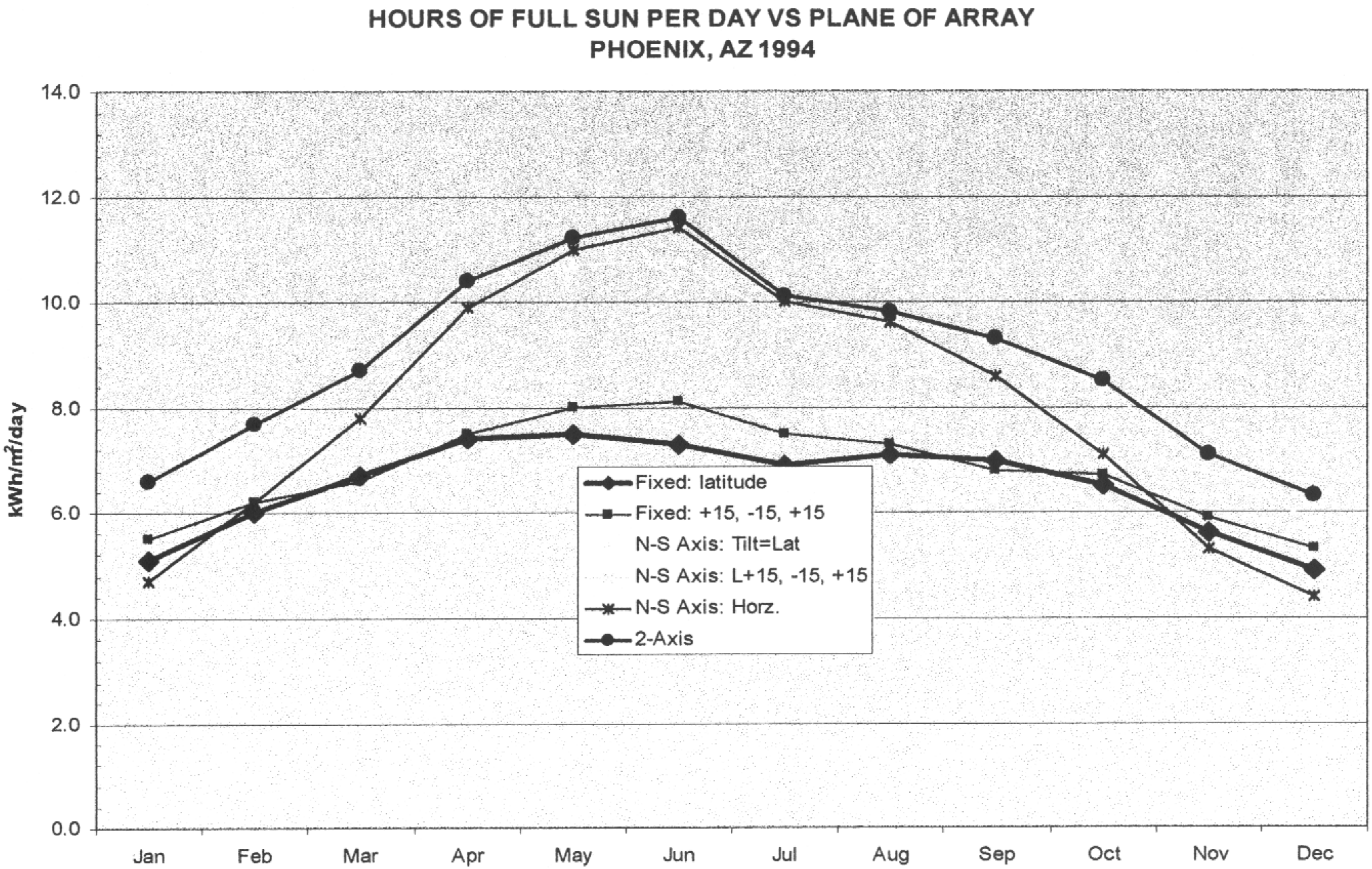

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MODULE MANUFACTURERS REPRESENTED ON THE TRACKER

- ASEA
- Astropower
- Golden Genesis (*formerly Photocomm*)
- Siemens
- Solarex

MODULES FIELDED IN TEMPE, AZ AT APS STAR FACILITY

		ENCAPSULANT FORMULATION					
		Experimental				Control	
Manufacturer	Construction (Front → Back)	X9903P	X9923P	X9933P	X15303P	A9918P	15295P
B	G/E/C/E/F	-	2	2	2	12*	-
C	G/E/C/E/F	2	-	2	-	-	2
D	F/E/C/E/A	2	2	2	-	-	2
E	G/E/C/E/F	-	-	-	4	-	4
F	G/E/C/E/F	2	-	2	2	-	2

Glass Encapsulant Cells Film Aluminum * 6 with CeO^2 glass ** 6 without CeO^2

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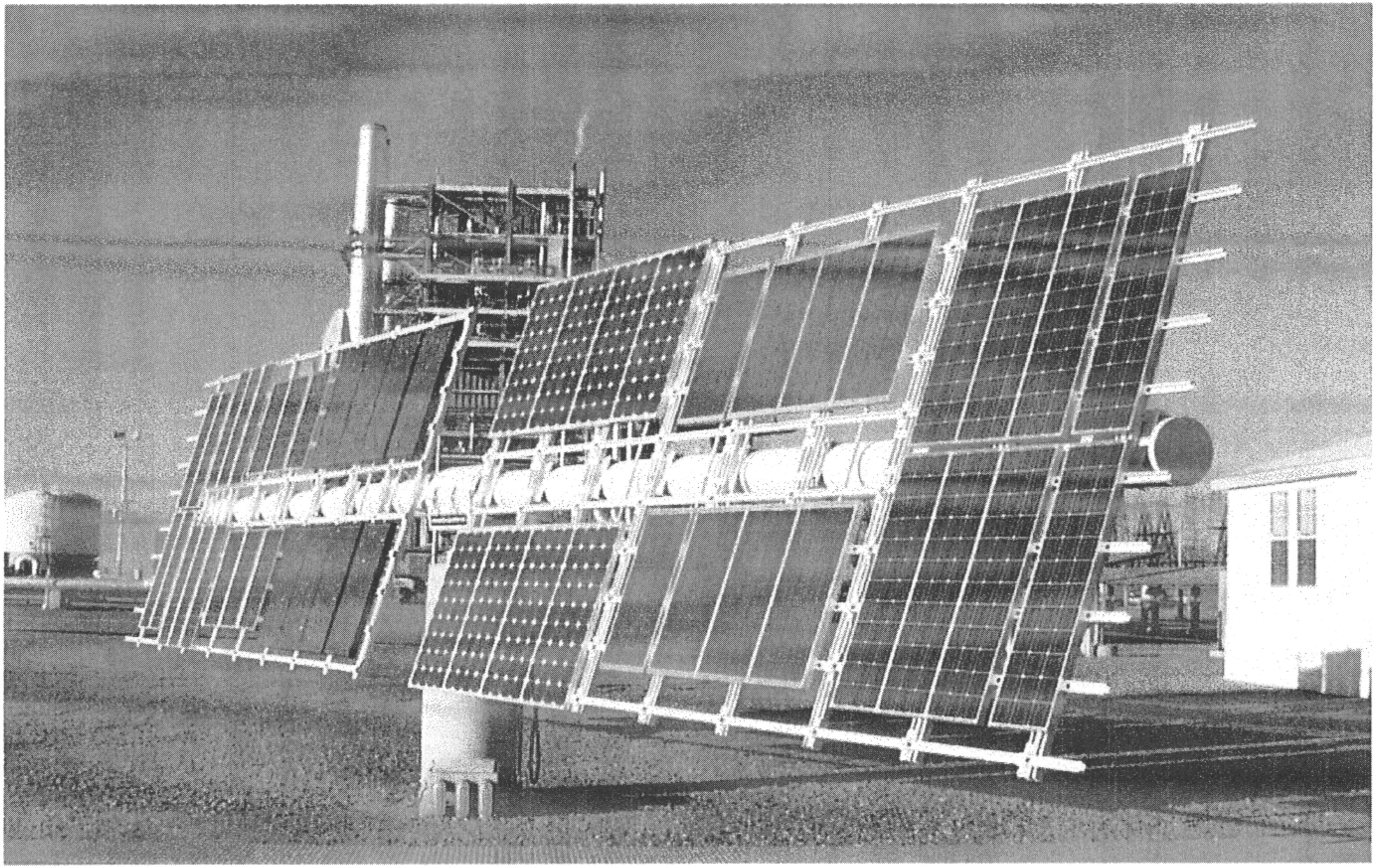
TRACKER 17 AT THE APS STAR FACILITY



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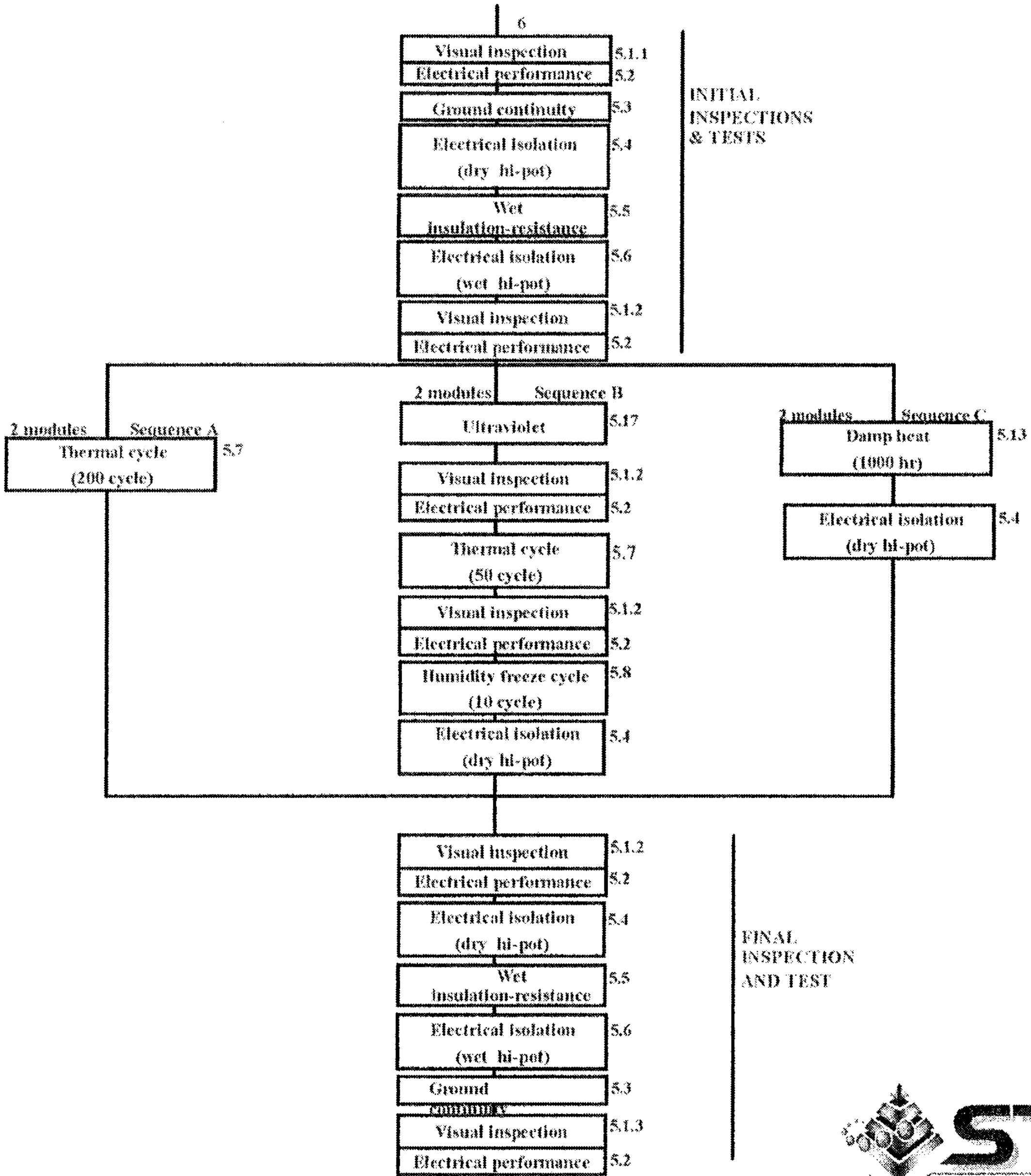
STR IEEE 1262 Project



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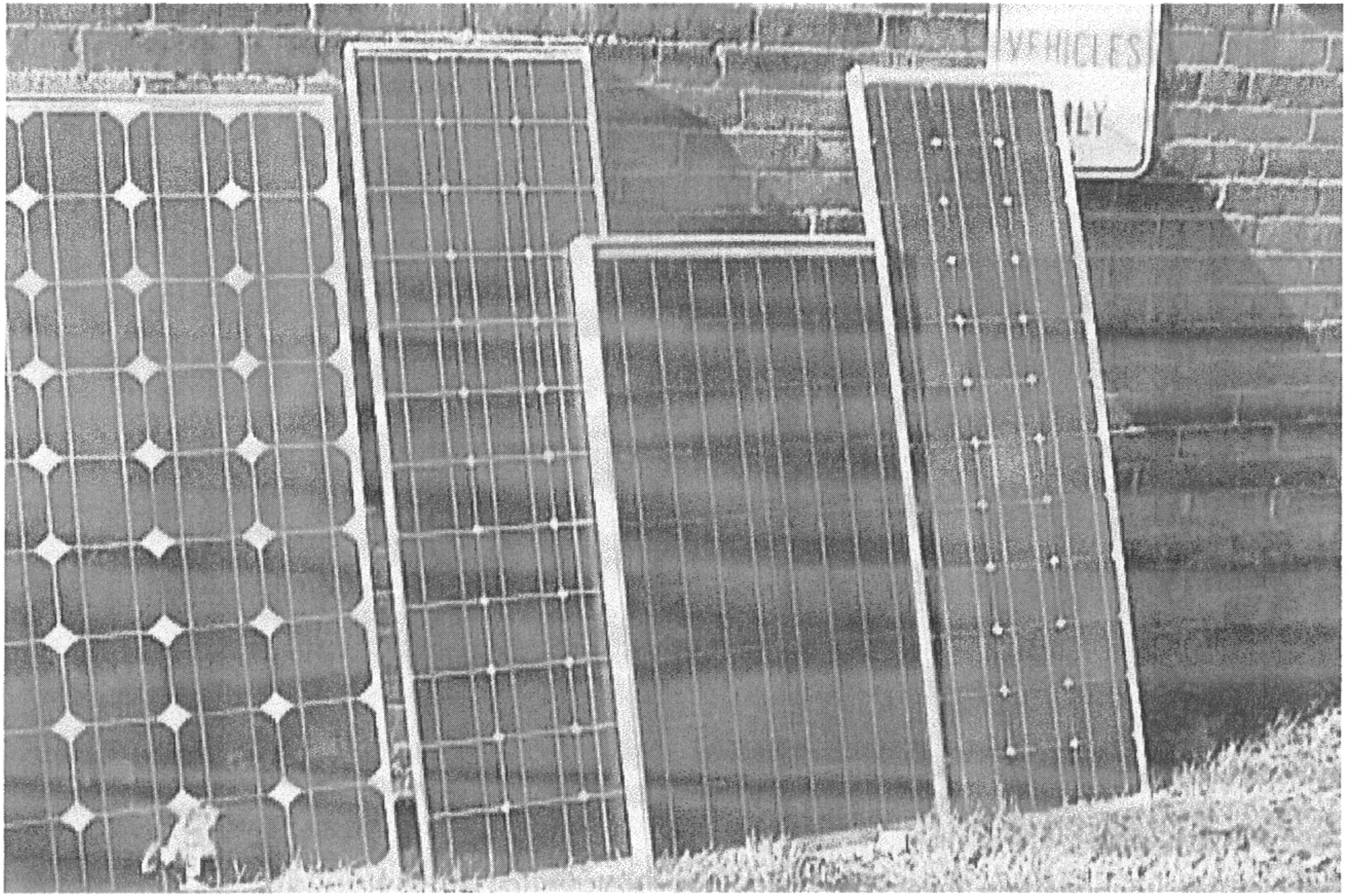
X9933P MODULES AFTER QUAL. TEST



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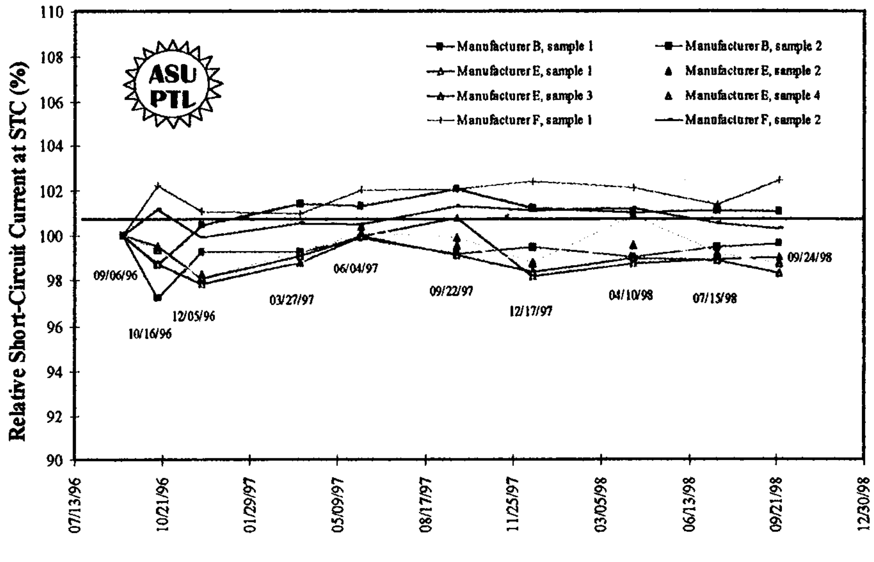
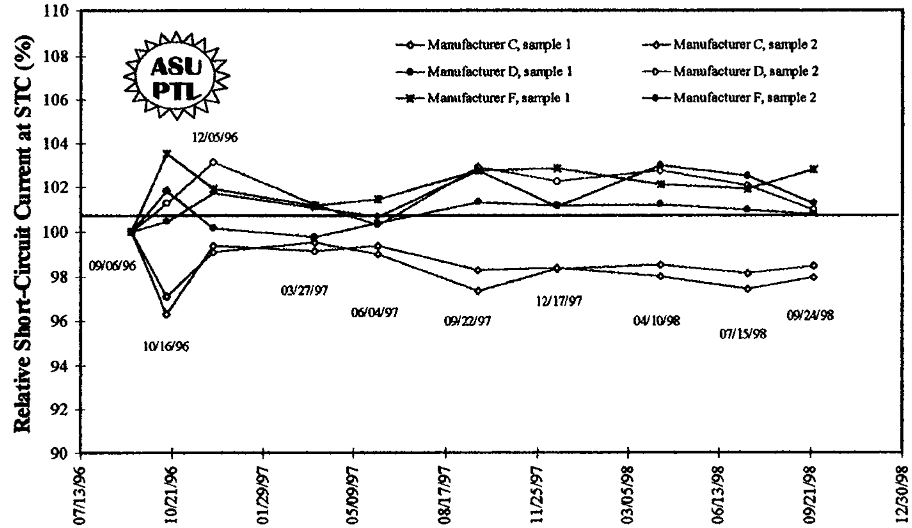
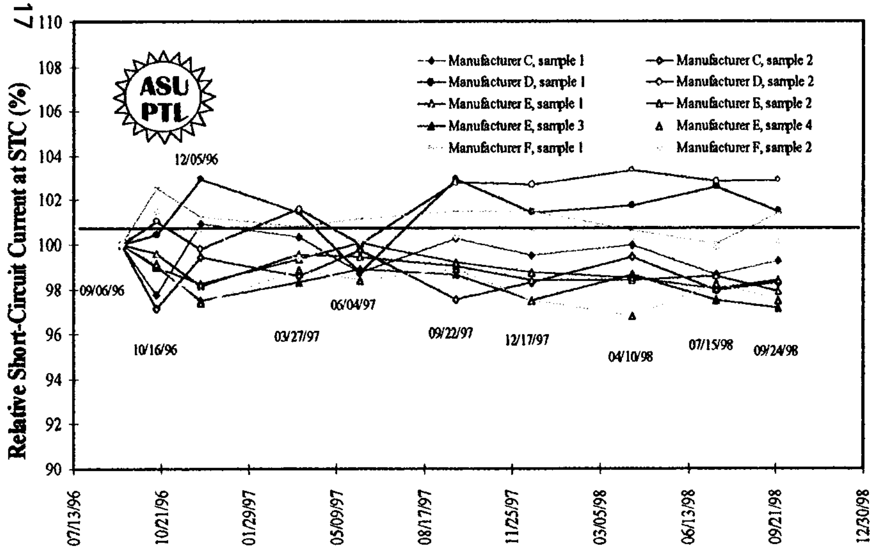
X15303P



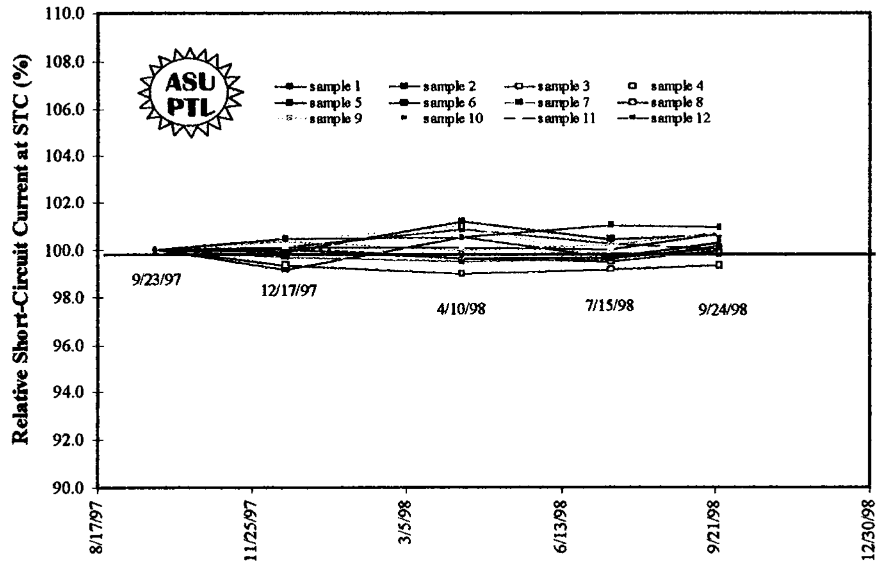
X9903P



X15295P



Control Modules (Manufacturer B)



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EFFECT OF QUAL TEST CONDITIONS ON ADHESION

S/N	IEEE 1262 SEQUENCE	ENCAPSULANT	TO GLASS	TO CELL	TO INTER.	TO COVER OR BACKING FILM	COLOR OF BACKING/COVER FILM
448	A	X9903P	2 - 3	1	1	1	Colorless
452	C	X9903P	3	1 - 2	1	4	Slgt brown
32	A	X9903P	1 - 2	2	3	1-2	Colorless
34	B	X9903P	2	1	2 - 3	2	Colorless behind cell
35	C	X9903P	1 - 2	1 - 2	3	4	Slgt brown
02	A	X9903P		1 - 2	3	1	Colorless
04	B	X9903P		1 - 2	3	1	Colorless
05	C	X9903P		1 - 2	3	1	Slightly yellow
6	B	X9923P	2	2	2	3	Colorless
2	C	X9923P	2 - 3	1 - 2	3	3	Colorless
22	A	X9923P		1 - 2	3 - 4	1	Colorless
26	C	X9923P		1 - 2	3 - 4	3	Slightly yellow

IEEE 1262: A=T cycle; B=UV; T cycle; C=85/ 85

Qualitative: 1=excellent, 2=v. good, 3=good, 4=fair, 5=poor

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EFFECT OF QUAL TEST CONDITIONS ON ADHESION

S/N	IEEE 1262 SEQUENCE	ENCAPSULANT	TO GLASS	TO CELL	TO INTER.	TO COVER OR BACKING FILM	COLOR OF BACKING/COVER FILM
2	A	X15303P	2	2	3	3	Colorless
00140	B	X15303P	2	2	3	2 - 3	Colorless
00145	C	X15303P	2 - 3	2	3	3	Colorless
458	A	X15303P	2 - 3	1 - 2	3	2 - 3	Colorless
446	B	X15303P	2 - 3	1 - 2	2 - 3	2 - 3	Colorless
447	C	X15303P	2 - 3	1 - 2	4	4	Slgt brown
22	A	X15303P	1 - 2	2	3	1-2	Colorless
26	C	X15303P	2	1 - 2	3 - 4	4 - 5	Slgt brown
12	A	X15303P	-	1 - 2	3 - 4	2 - 3	Colorless
14	B	X15303P	-	1	3 - 4	2 - 3	Colorless
22	A	X15303P	3	3	3	1 - 2	
26	C	X15303P	3	3	2	1 - 2	

IEEE 1262: A=T cycle; B=UV; T cycle; C=85/ 85

Qualitative: 1=excellent, 2=v. good, 3=good, 4=fair, 5=poor

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SUMMARY OF ADHESION TESTS AFTER IEEE 1262
(Generally for X15303P, X9903P, X9923P)

	General	Exceptions	Problem Sequence	Comments
Glass	Good - V. Good	None	None	N/A
Cells	V. Good - Excellent	Manufacturer H With X15303P	None	Best overall adhesion was to cells
Interconnects	Fair - Excellent (variable)	None	A, B, C	Suspect surface treatment, solder flux
Back/Cover Films	Good - Excellent	Manufacturer E & F	C	Adhesive tie layer on back laminate degrades in damp heat. Tie layer discolored in samples with poor adhesion

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CONCLUSIONS

- As of September 1998, None of the modules on the tracker have exhibited measurable power loss.
- 2-axis tracking at the test site is exposing the modules to 40% more energy than a typical fixed latitude mount.
- No visible discoloration is apparent in any of the tracker modules to date.
- Destructive interaction between the new encapsulants and module components has not been seen to date.
- X9903P and X15303P continue to be viable new encapsulant formulations
- Stray bullets don't kill Photocomm modules.

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CLOSING COMMENTS

- **Though our PVMaT program ended in 1997, STR will continue to fund this effort for the foreseeable future.**

- **We also expect to learn a bit about how the qualification tests, Xenon Arc, and EMMA test compare with actual outdoor exposure in Tempe, AZ.**

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Accelerated Aging of PV Encapsulants by High Intensity UV Exposure

Objective:

- Develop a screening test to differentiate UV degradation susceptibility of current and candidate PV encapsulation polymers
  - Quantify the effect of UV degradation by measuring adhesion
  - Not a lifetime predictor test

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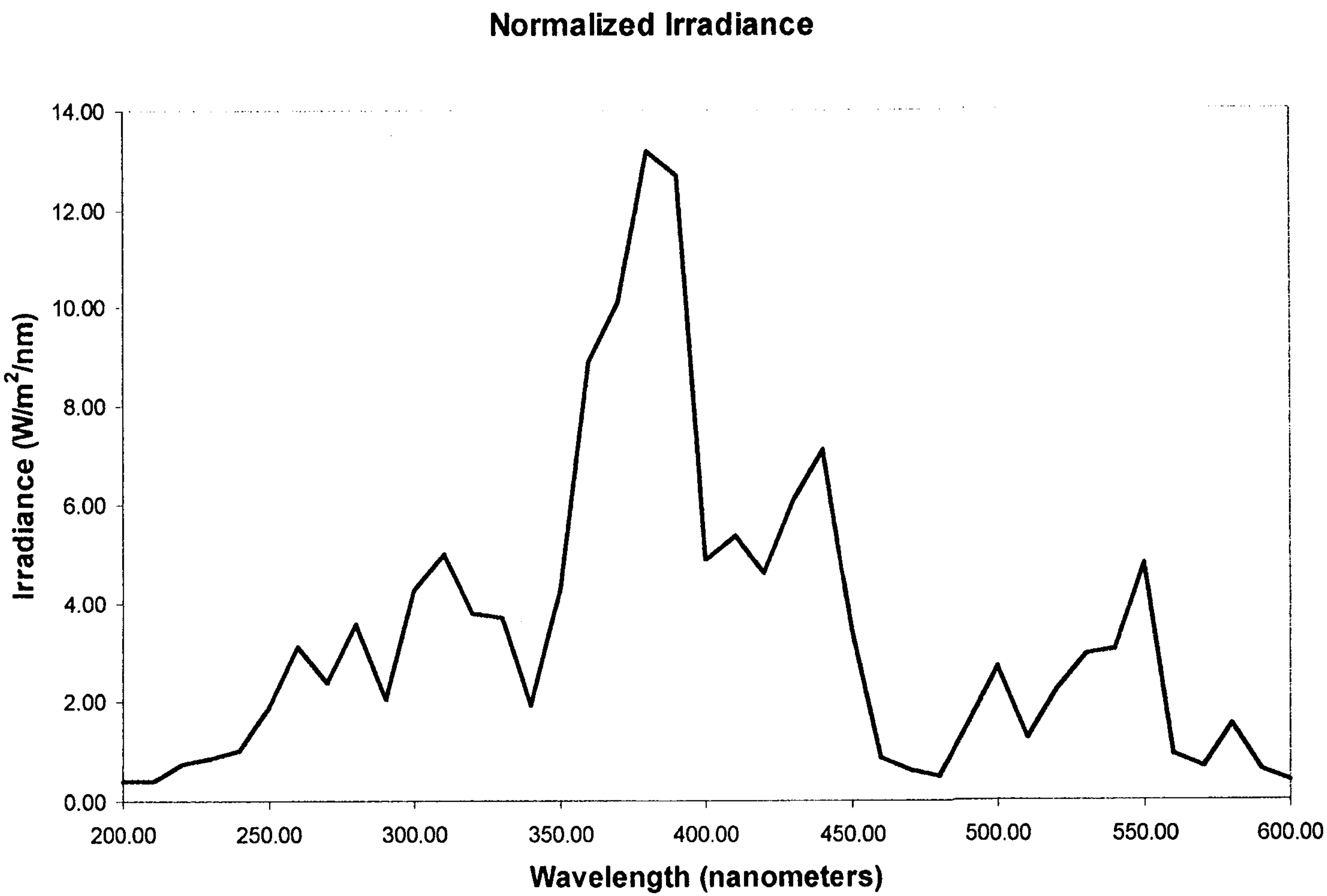
Methodology

- Prepare test samples
  - Laminate multiple 2 x 2 in. piece of quartz to 2 x 2 in. piece of glass using each test encapsulant
- Stress
  - Expose each sample to UV source of known irradiance for pre-determined time intervals
- Measure adhesion
  - "Lap-shear" fixture
  - Calibrated Tinius Olsen force instrument



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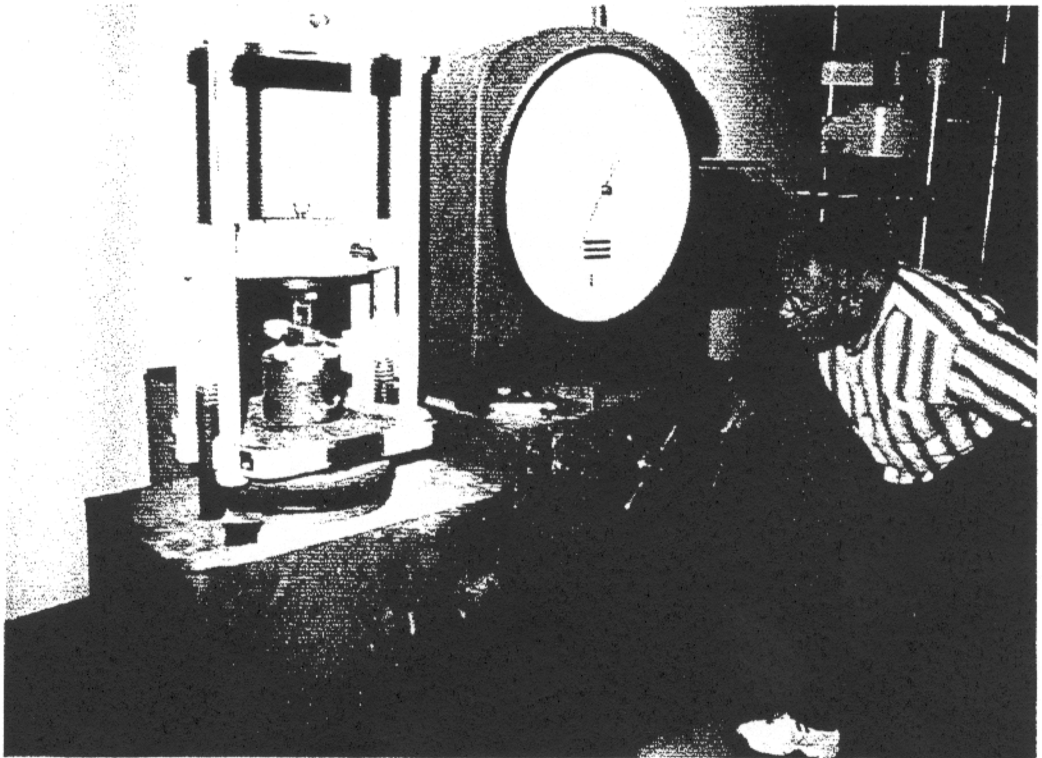

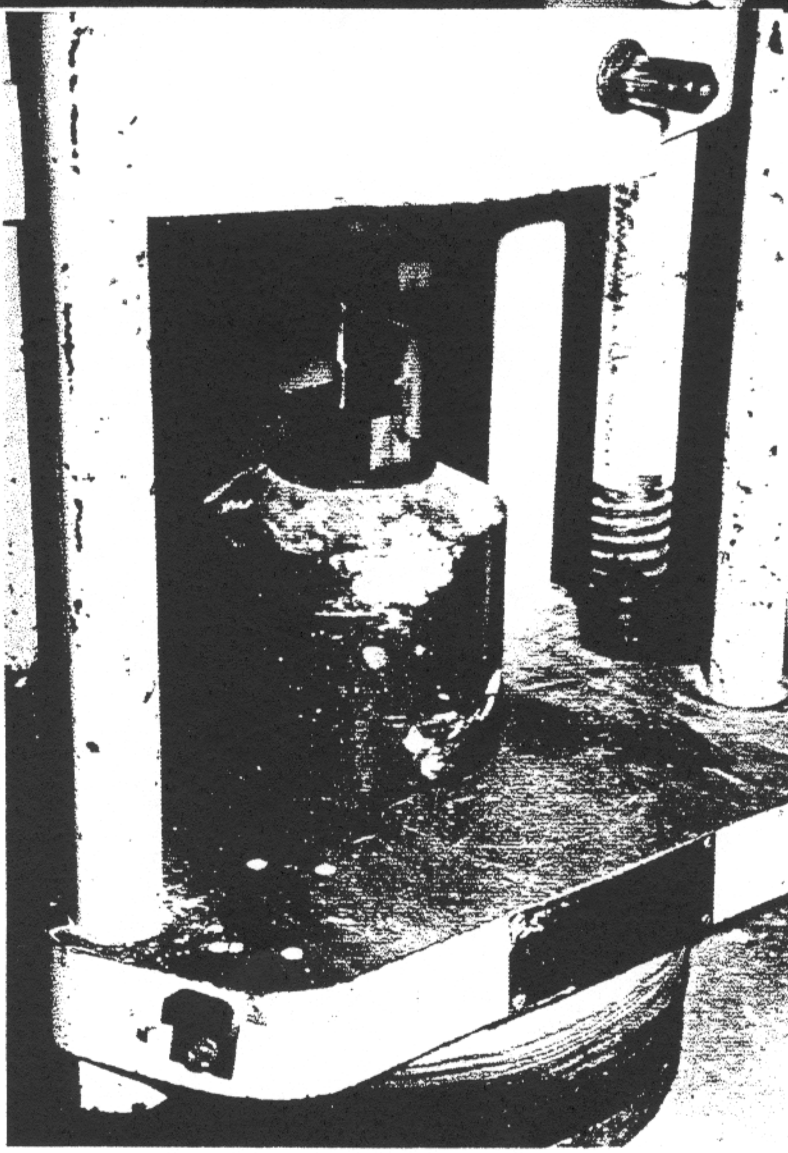

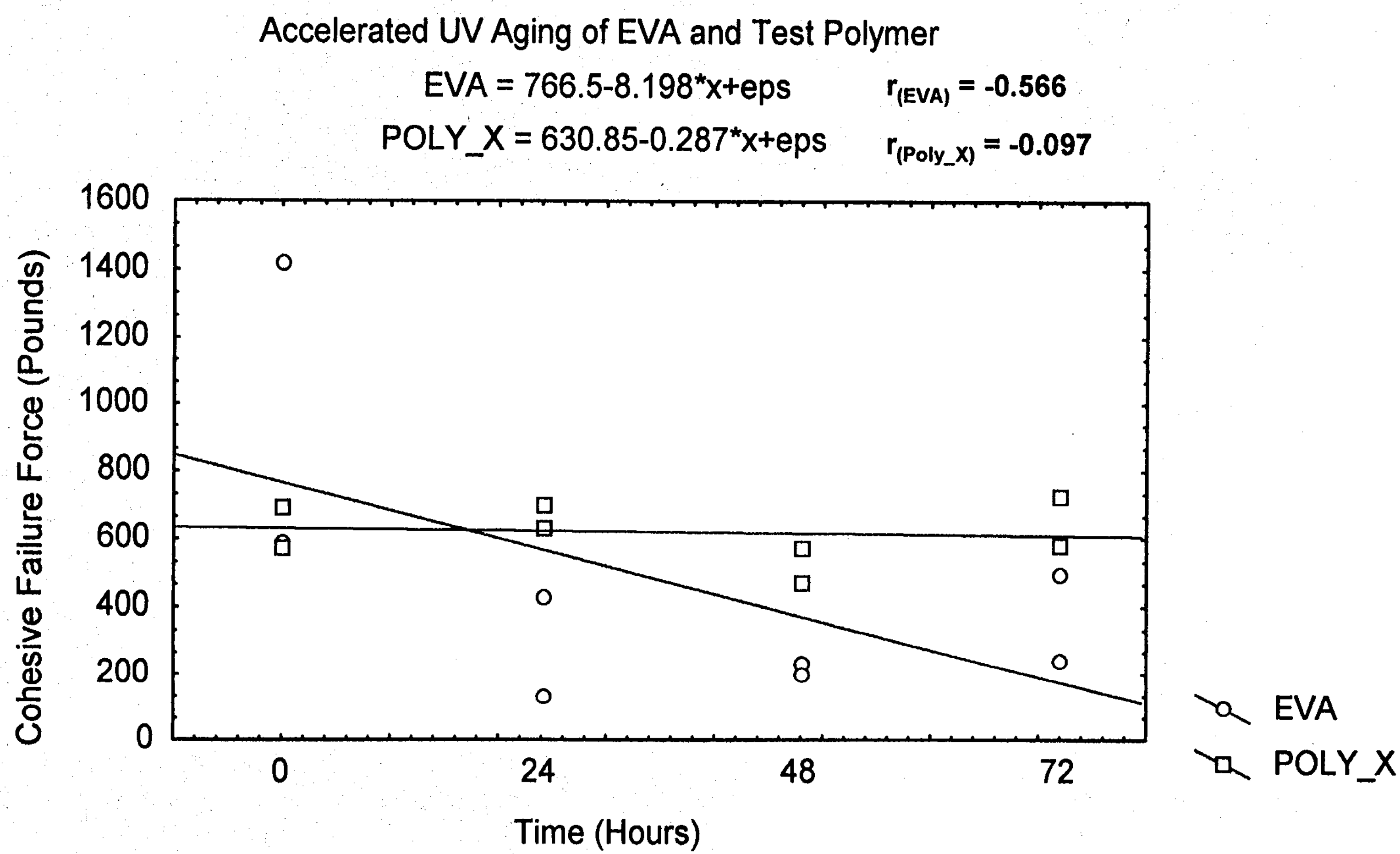

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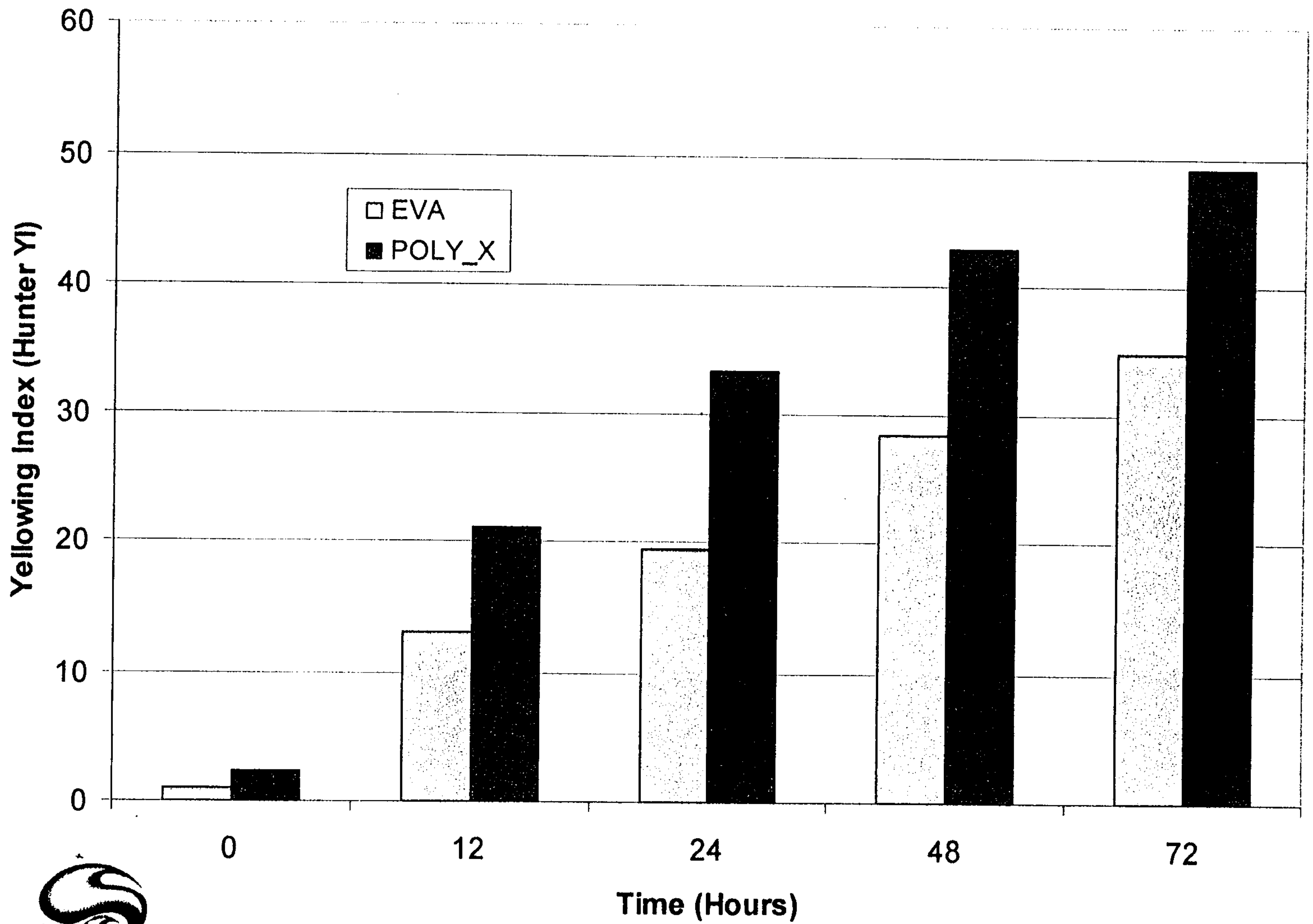
Yellowing Index Results



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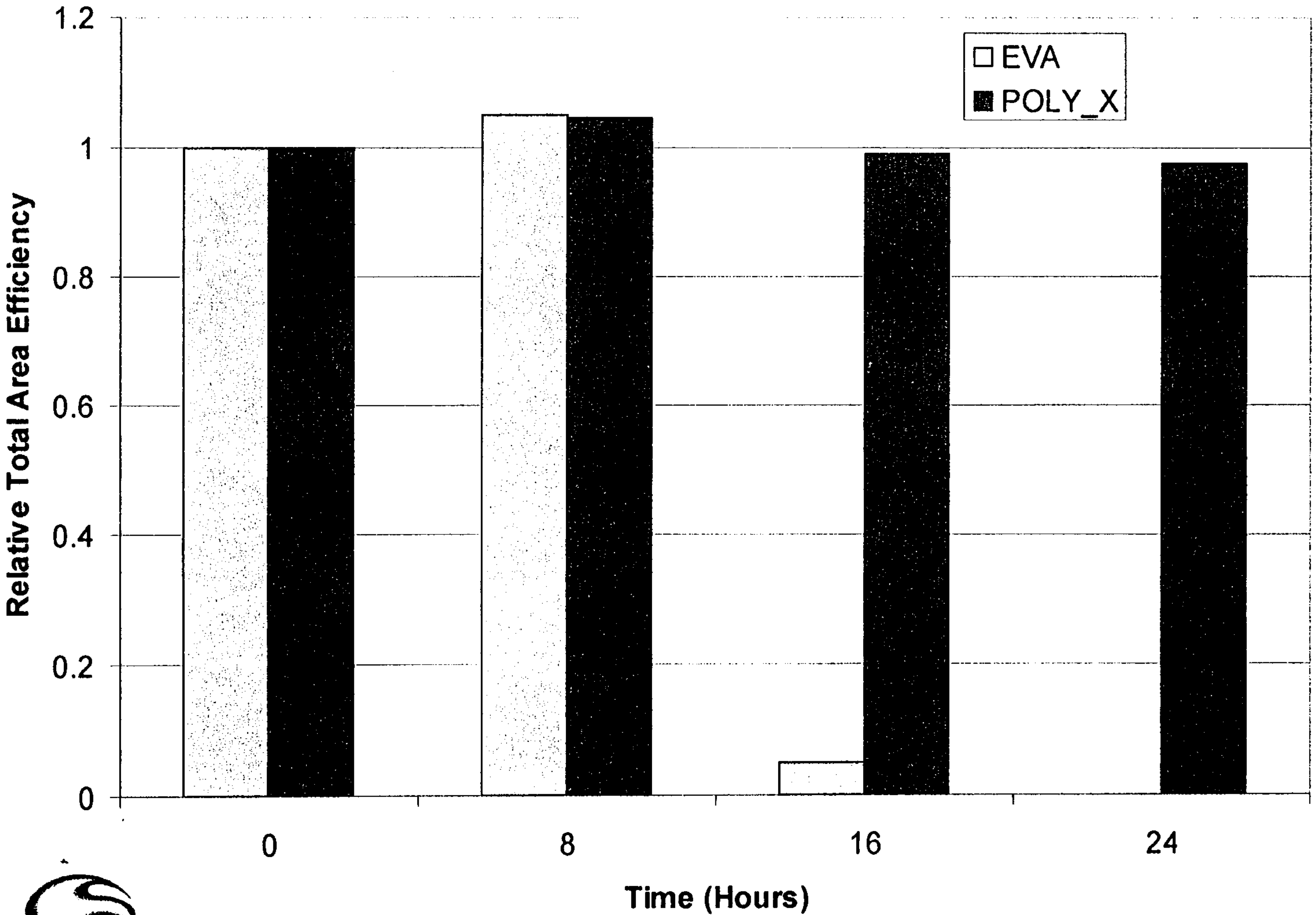
Relative Performance Results



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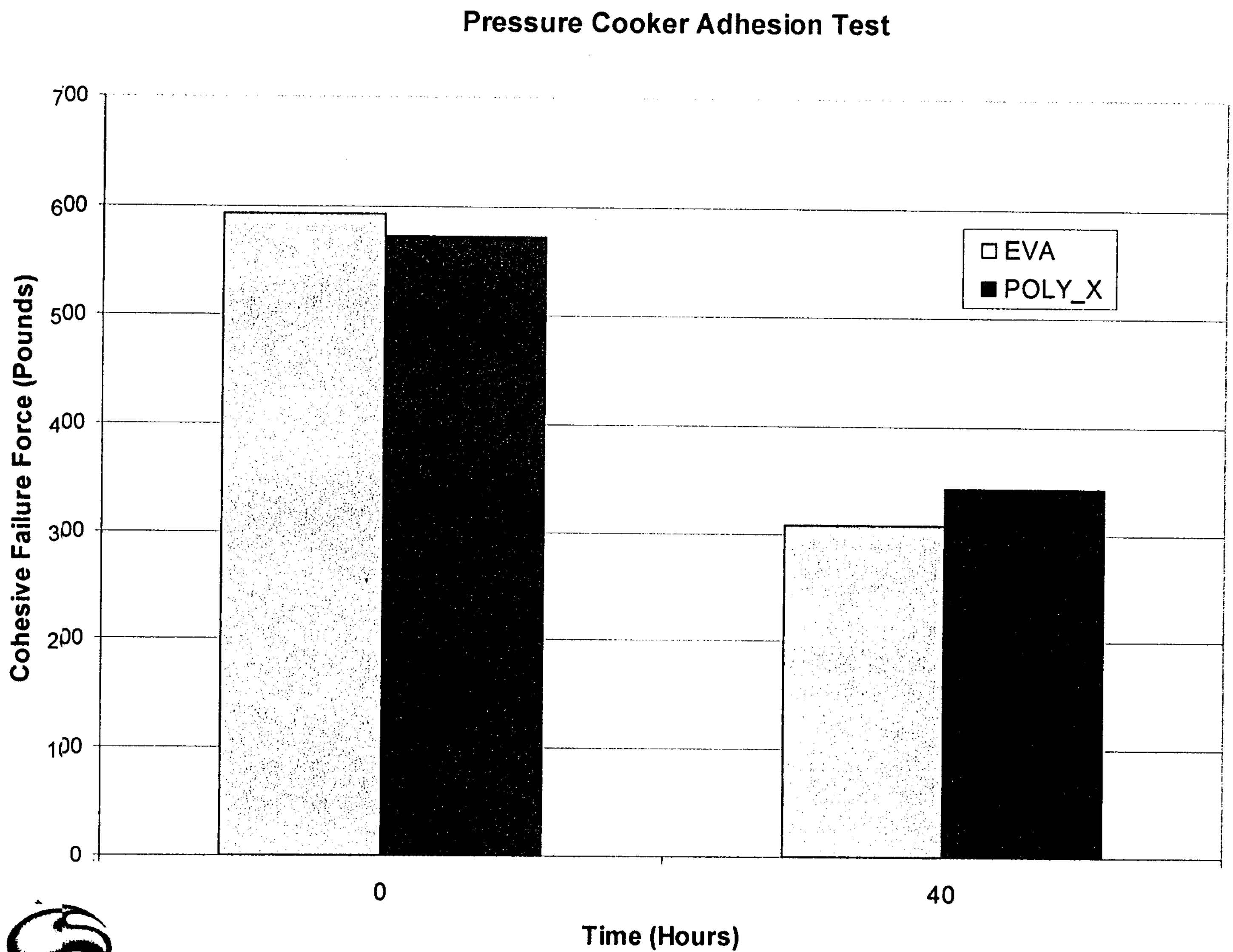

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Summary - Lessons Learned

- Accelerated UV aging method can be used as an indicator of polymer degradation susceptibility
- Polymer yellowing may not correlate to loss of adhesion
- Polymer degradation can affect device performance
- Alternative robust PV encapsulation polymers *do* exist

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SIEMENS

Siemens CIS Module Reliability Testing

Dennis Willett
Siemens Solar Industries
Camarillo, California USA

Prepared for the
1998 Photovoltaic Performance and Reliability Workshop
November 3-5, 1998
Cocoa Beach, Florida

This work was supported by the National Renewable Energy Laboratory under the Thin Film Photovoltaic Partnership Program

Acknowledgements

- The author gratefully acknowledges NREL for measurement and analytical assistance.
- This work was supported in part by the National Renewable Energy Laboratory subcontract No. AZF-5-14142-03.
- I also appreciate the assistance of my coworkers at Siemens whose work is presented here.

SIEMENS

Project Goals

- Produce modules with an outdoor life measured in decades.
- Keep package cost low.

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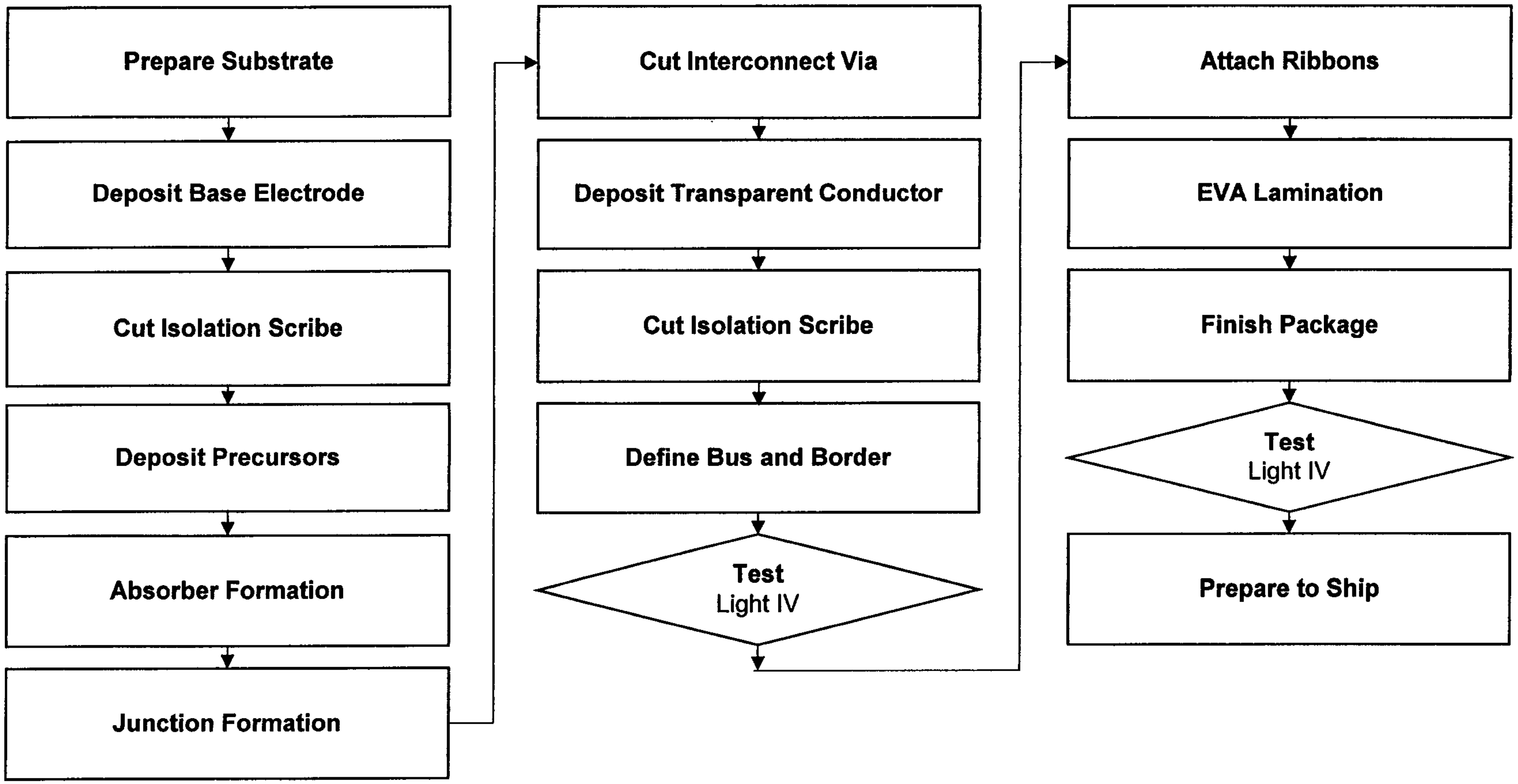
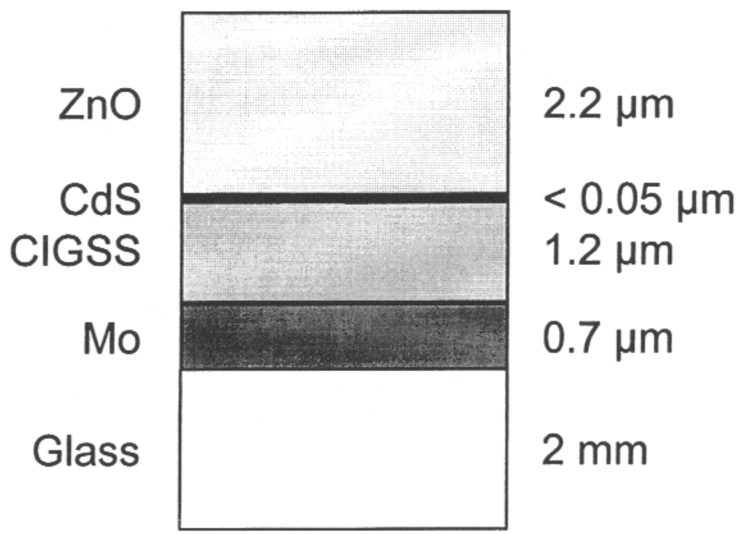
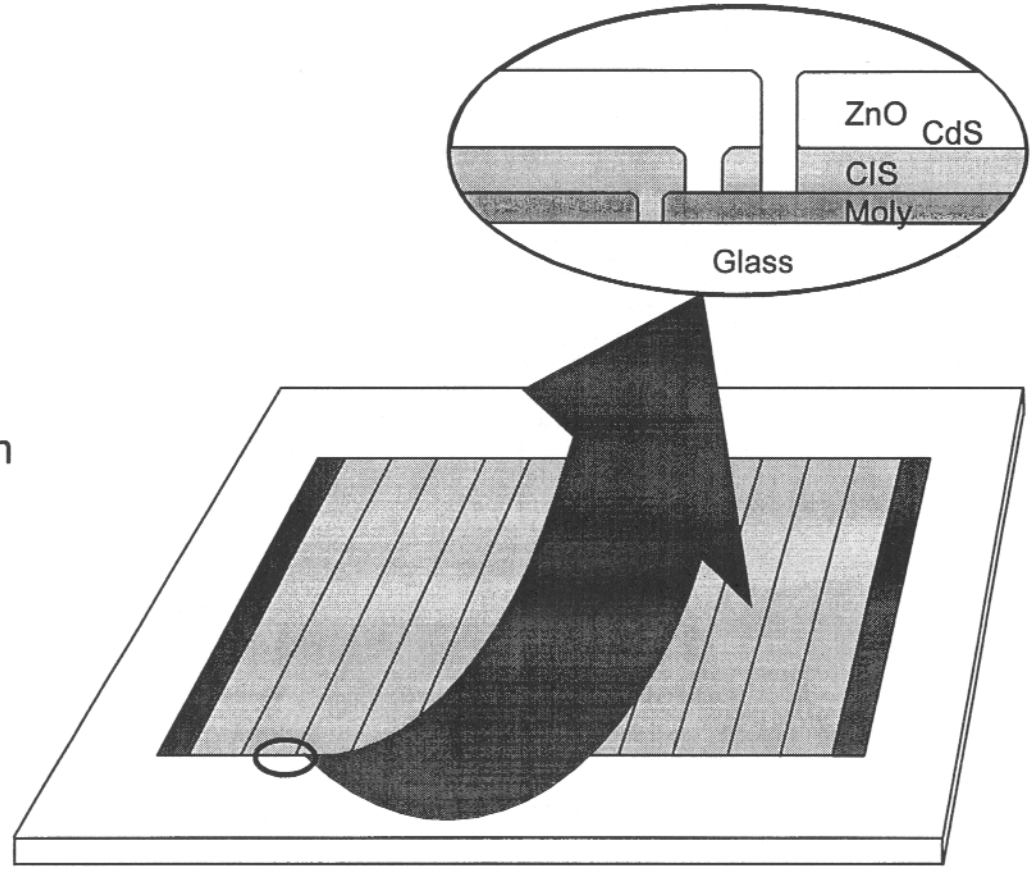
CIS Module Process Sequence



CIS Cell and Module Structure

CIGSS Solar Cell Structure
CIGSS = $Cu(In, Ga)(Se,S)_2$





CIS Circuit Plate Schematic

Environmental Qualification Tests
First Results

- Hi Pot
  - Pass
- Temperature Cycle
  - Pass with transient loss & recovery
- Humidity Freeze
  - Most pass with transient loss & recovery
- 1000 hours damp heat
  - Most packages fail
  - Some designs pass with transient loss & recovery

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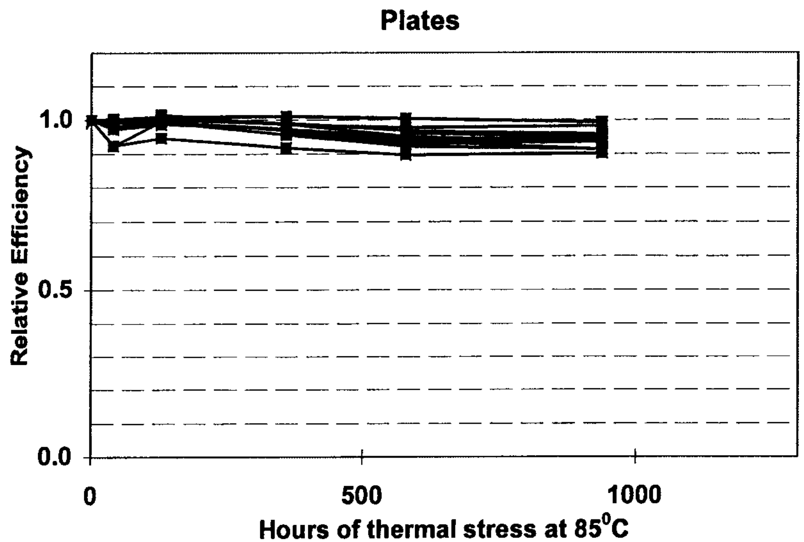
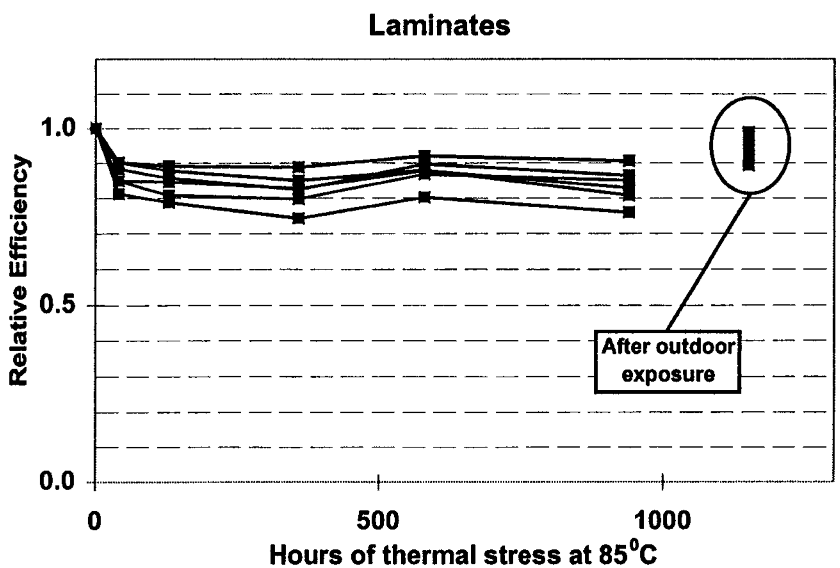
Transients in Circuit Plates and Laminates





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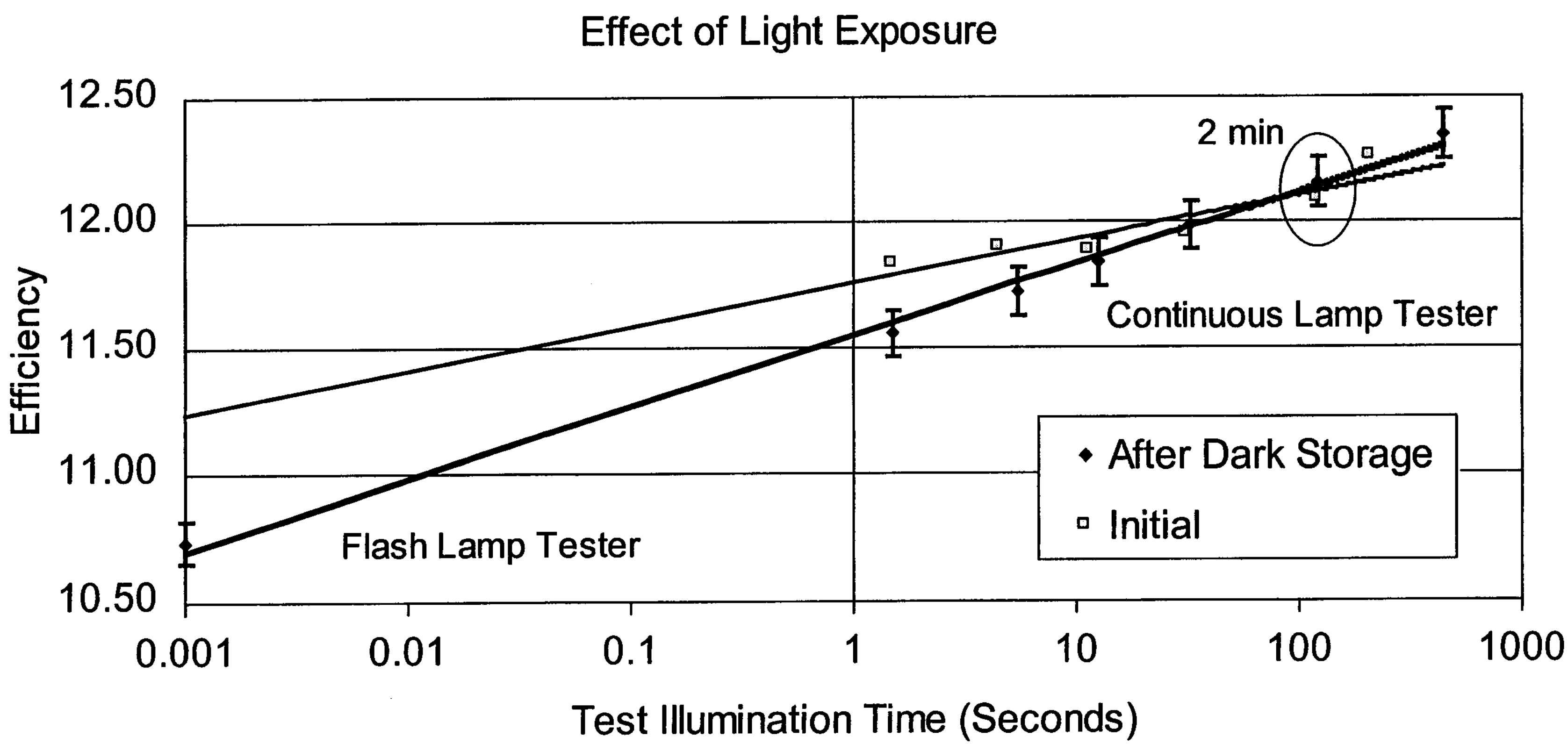
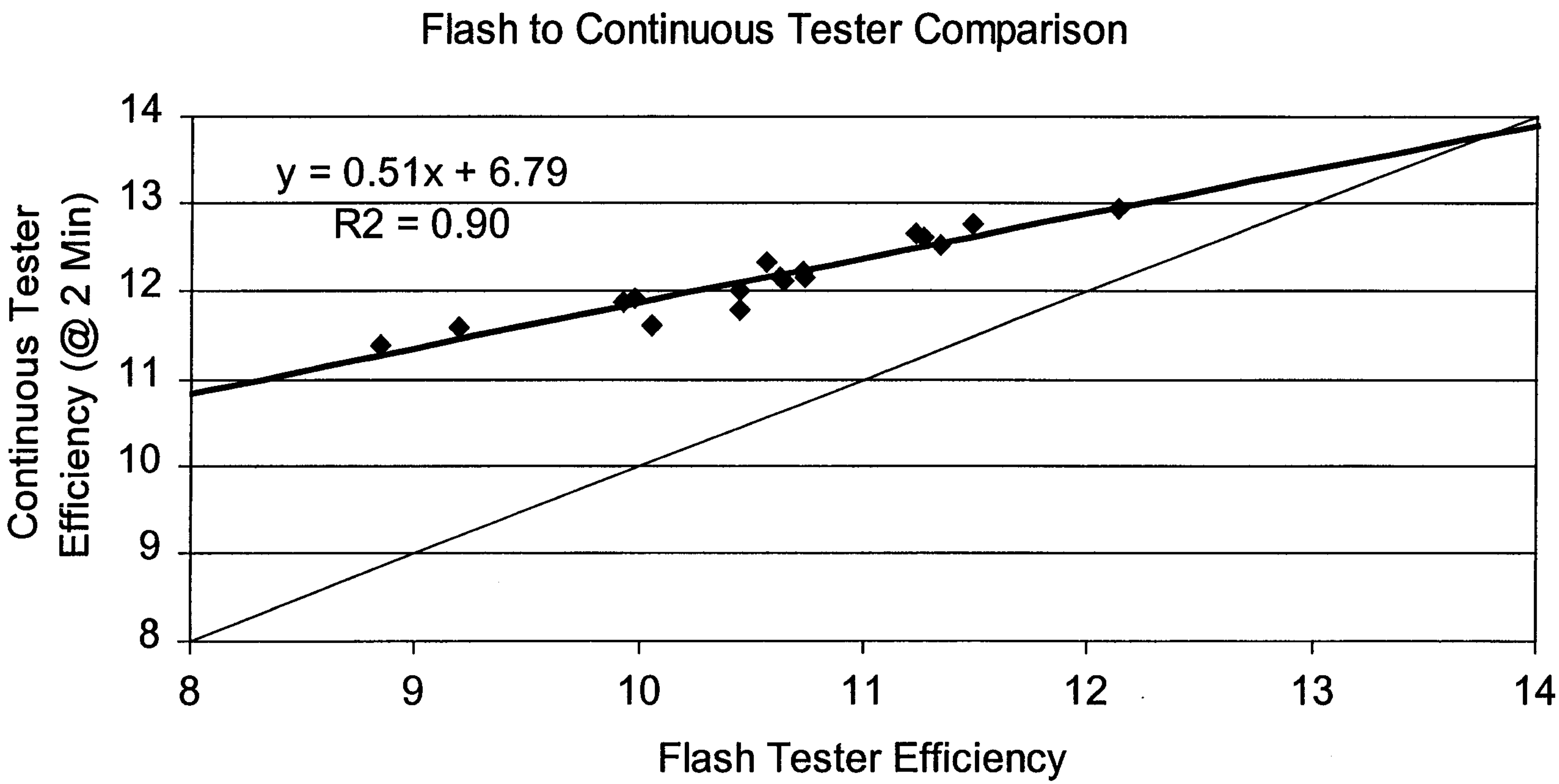
Transients Due to Light Soaking

Artifacts due to test methodology



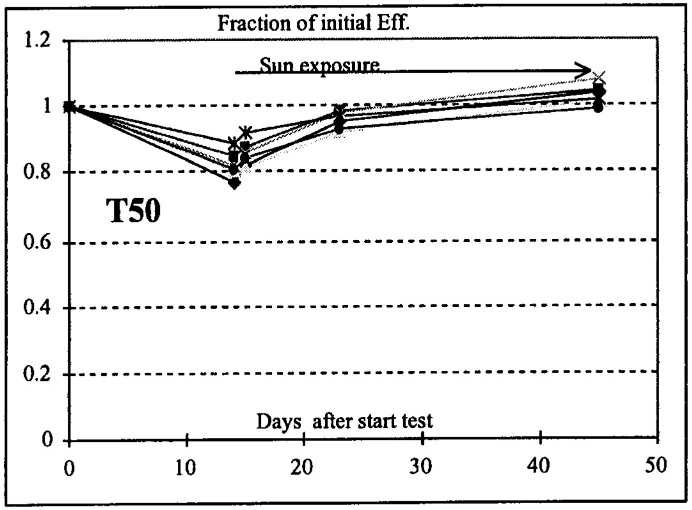
Transients Due to Light Soaking

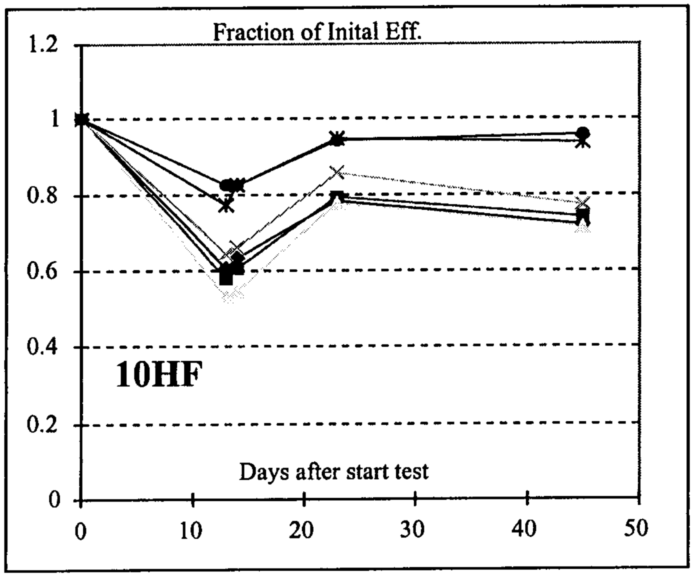
Artifacts due to test methodology

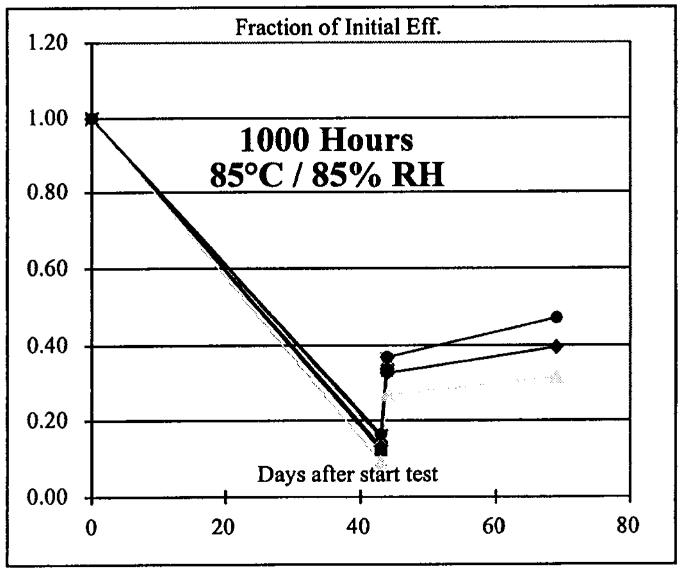


Results of Accelerated Testing

If moisture gets in the package, permanent damage occurs.







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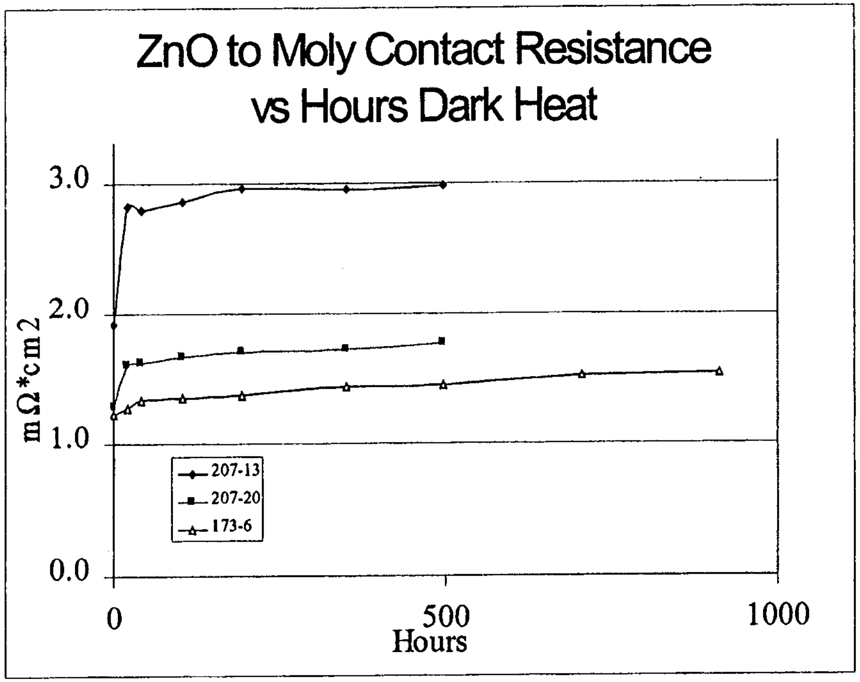
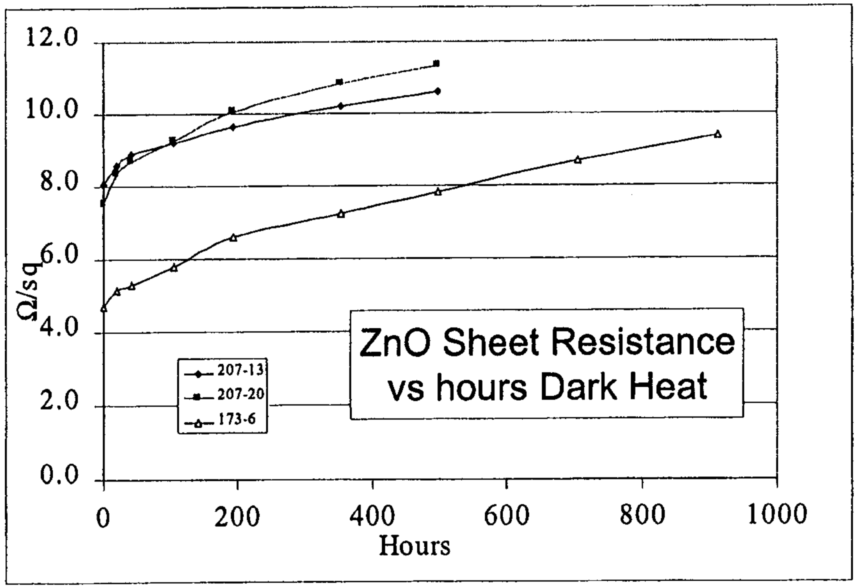
Transient Effects in ZnO



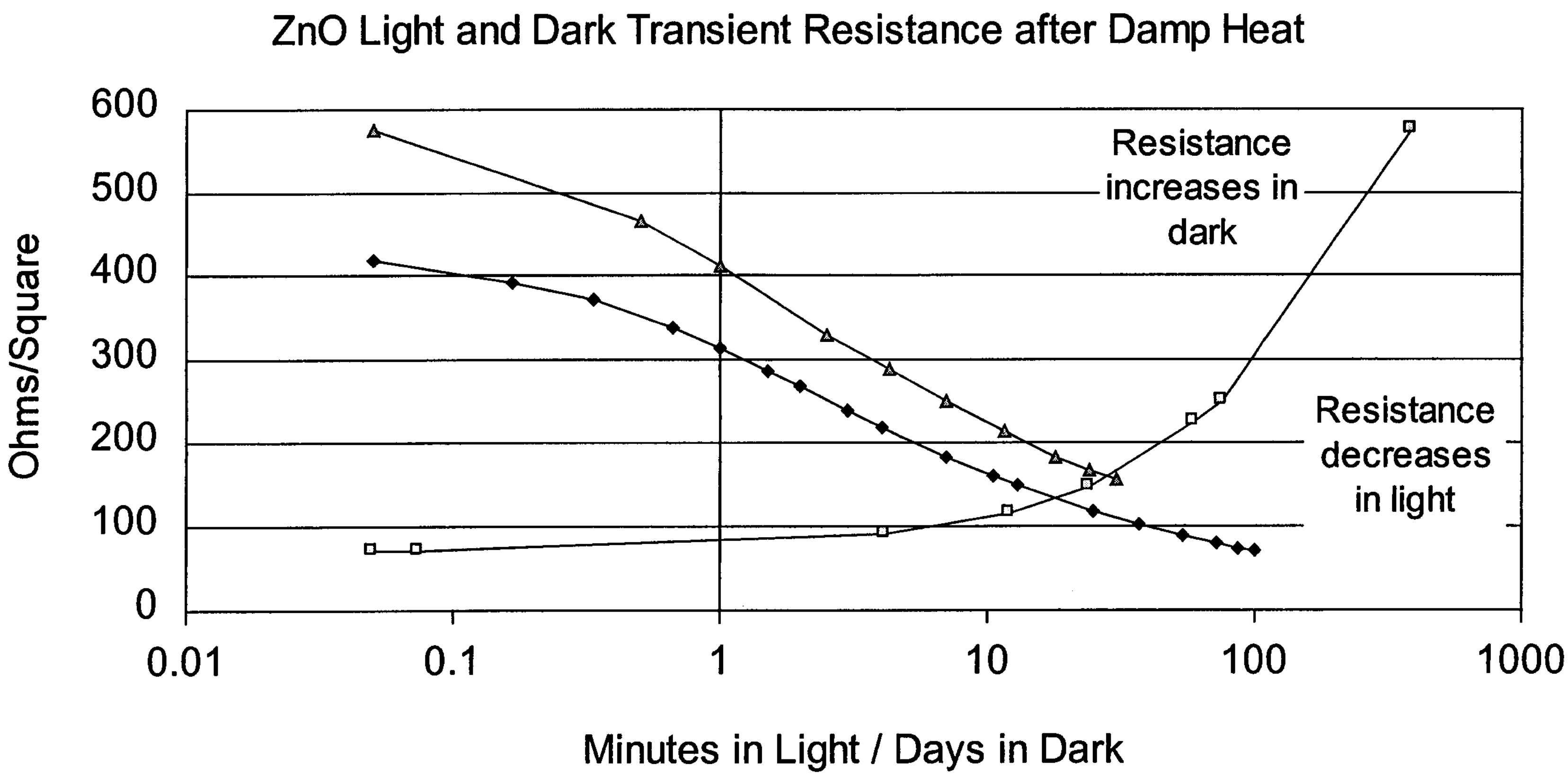
Laminated interconnect test structures show contact and sheet resistance increase in dark heat alone.



This may cause at most a drop of 7% in the FF.

Transients in ZnO

Transients are larger after humidity testing



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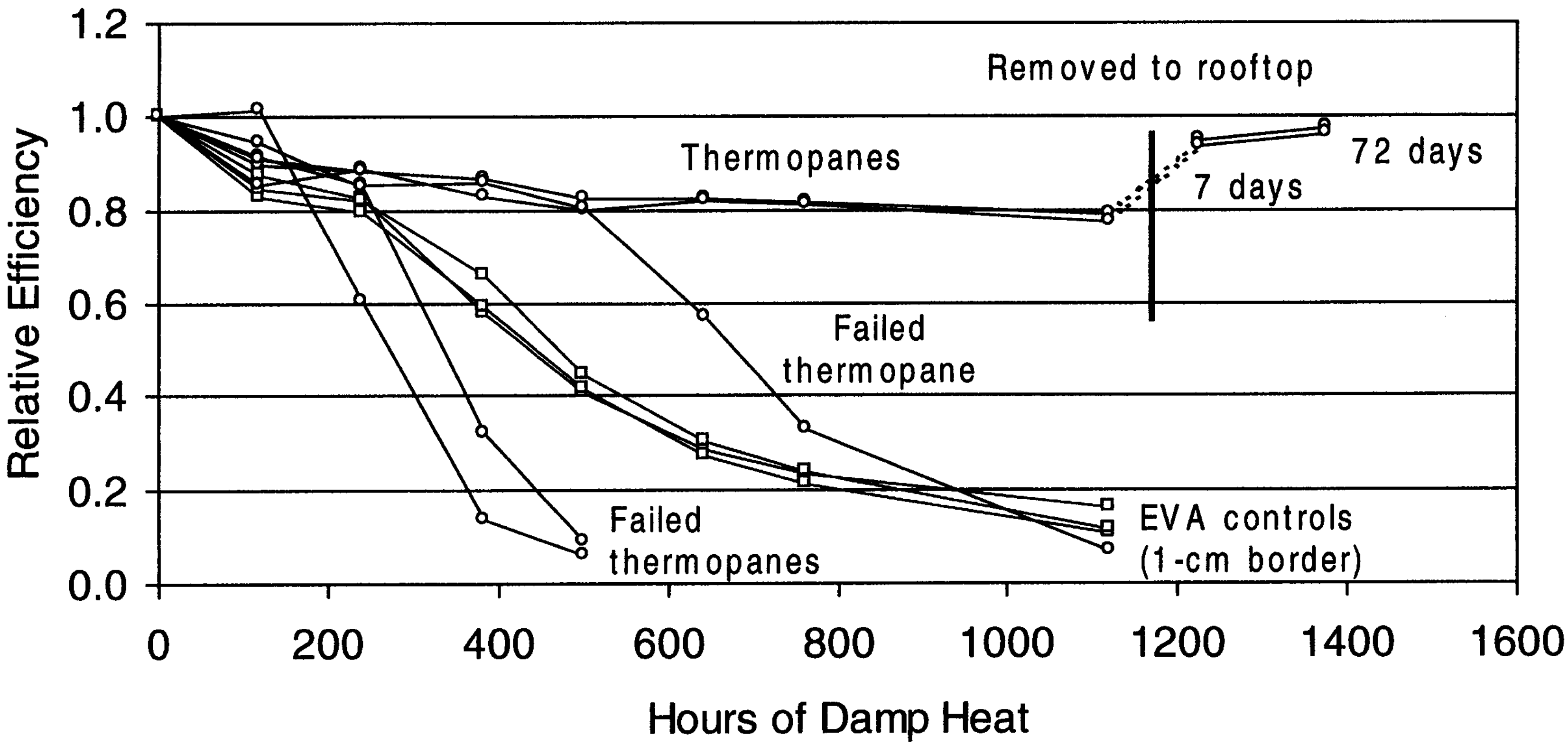
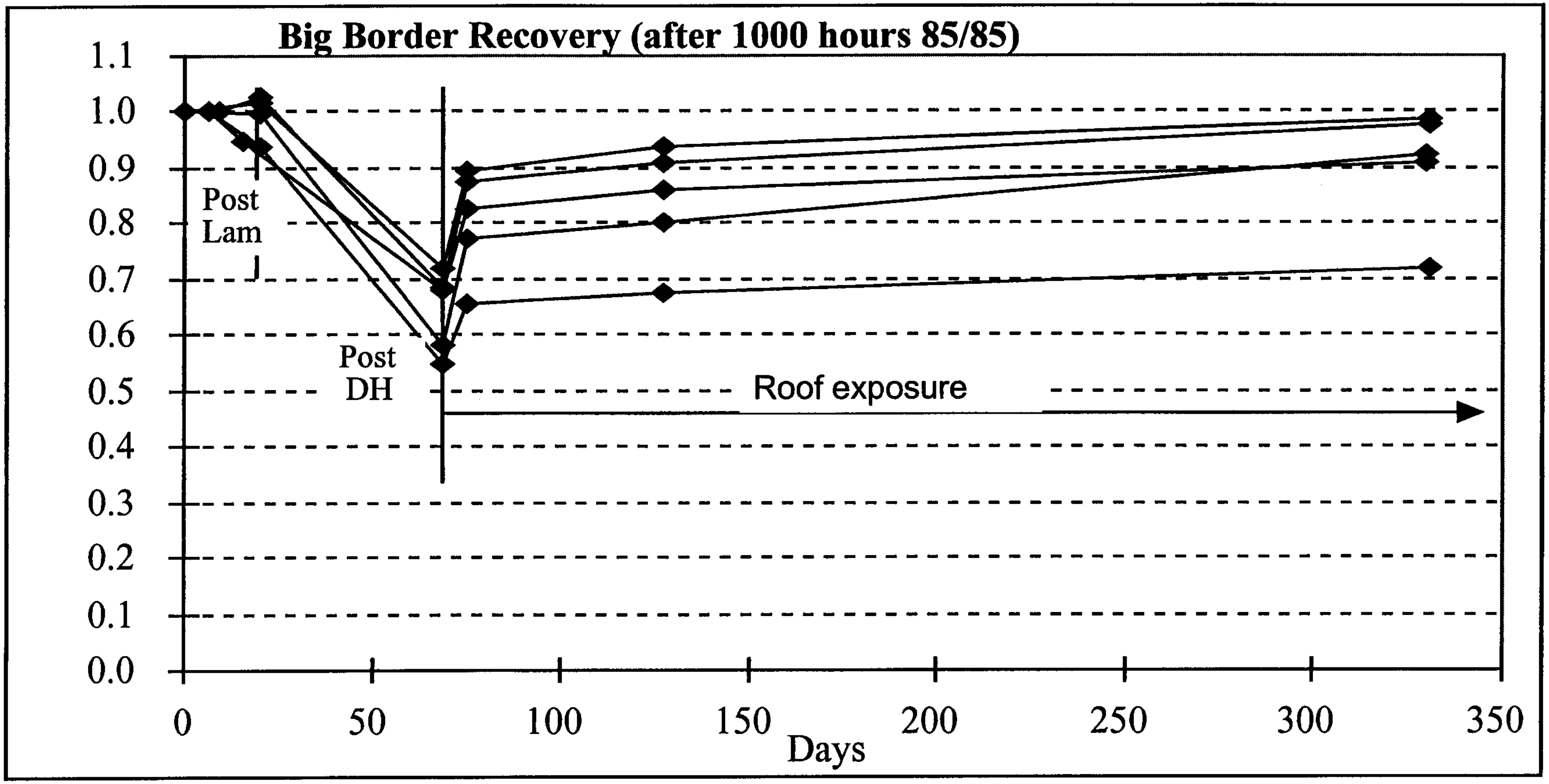
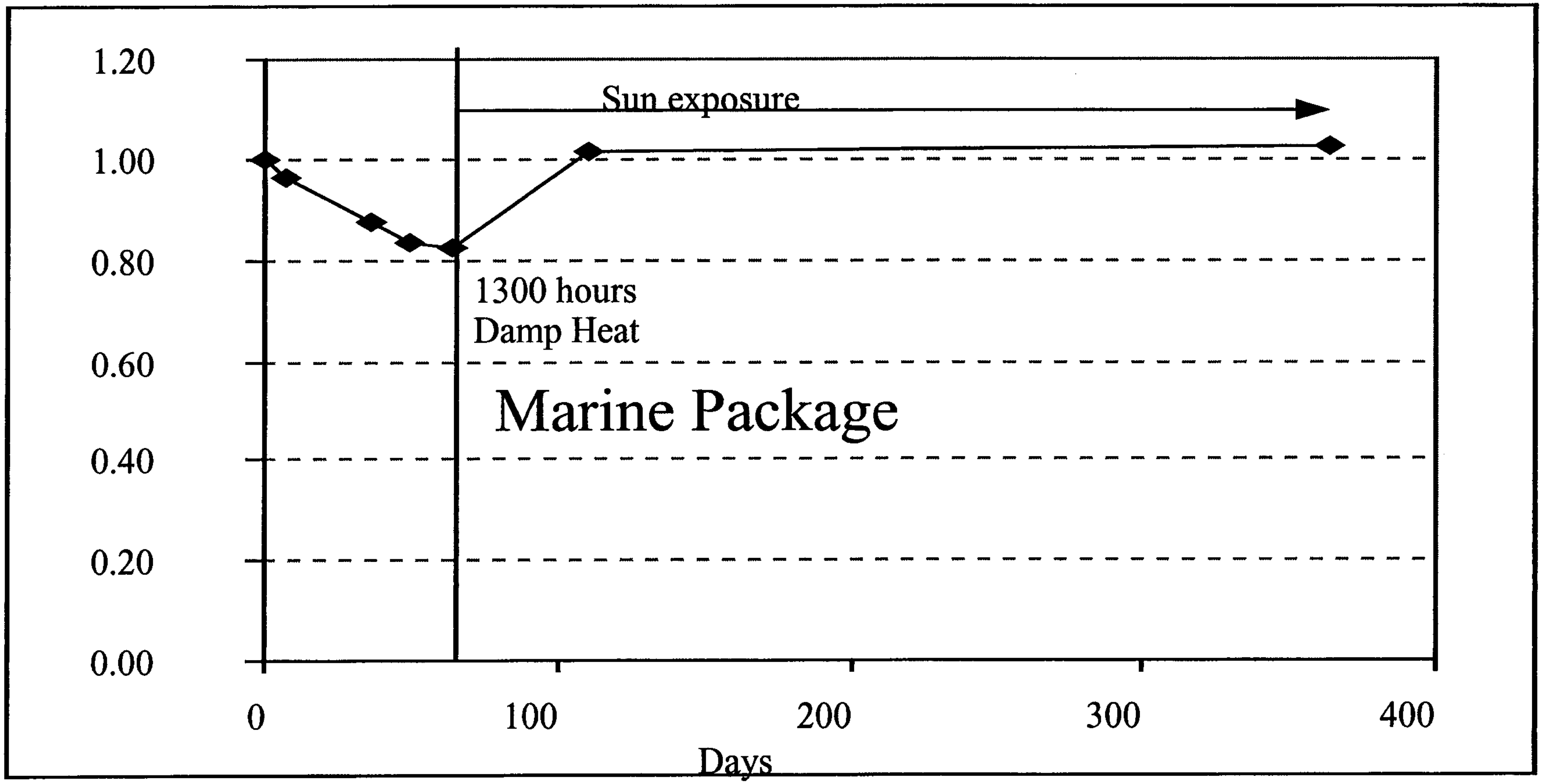
What Packages Keep Out Humidity?



What packages keep out humidity?



What Packages Keep Out Humidity?



New Approaches

Survey of Different materials

- 10 types of circuit coatings
  - Including epoxies, SiNx, SiOx, urethanes, acrylics, primers and plastics
- 7 types of pottants
  - EVAs and silicones
- 10 types of edge seals
  - Including tapes, RTVs, butyls and polysulfides
- 3 types of desiccants

Survey Results

- No one method or material alone would make a sufficient humidity barrier.
- Some combinations were quite good.
- Softer pottants may significantly reduced the thermal transient effects.

Softer Encapsulants and Edge Seals

- 13 of 16 ST5 modules encapsulated with a two part silicone had less than a -5% transient loss after 1000 hour dark dry heat even with a flash tester.
- One ST5 with silicone encapsulation and a polysulfide edge seal with desiccant passed 1000 hours damp heat with less than a -2% loss.

Current Status

- Current focus is on silicone pottants and sealing methods that are scaleable and economical.
- Placing 1kW arrays in harsh climates for more field experience.
- Some residual Isc losses are due to cover glass instability.
  - Glass develops a white flaky skin.
  - Glass transmission drops in sunlight.

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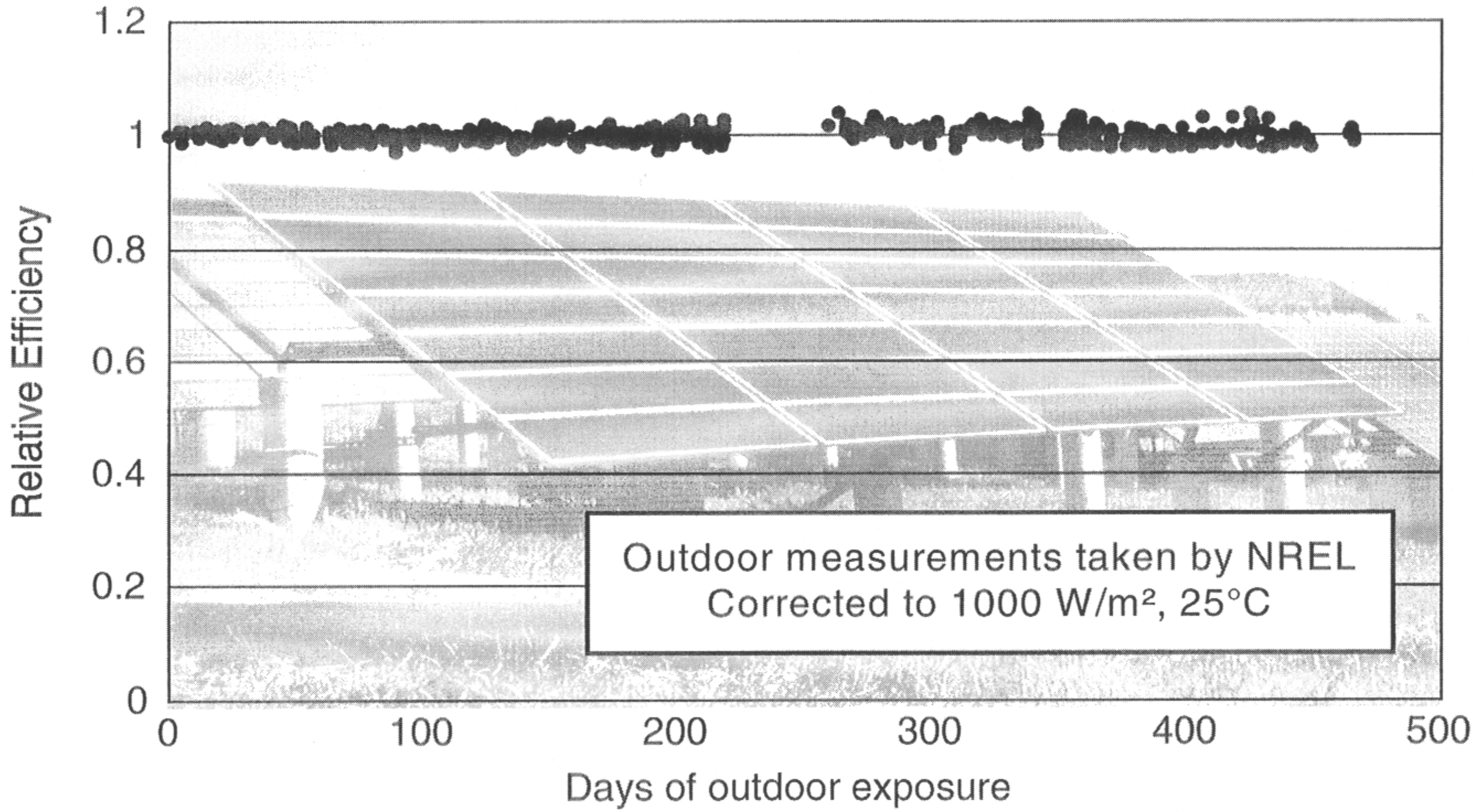
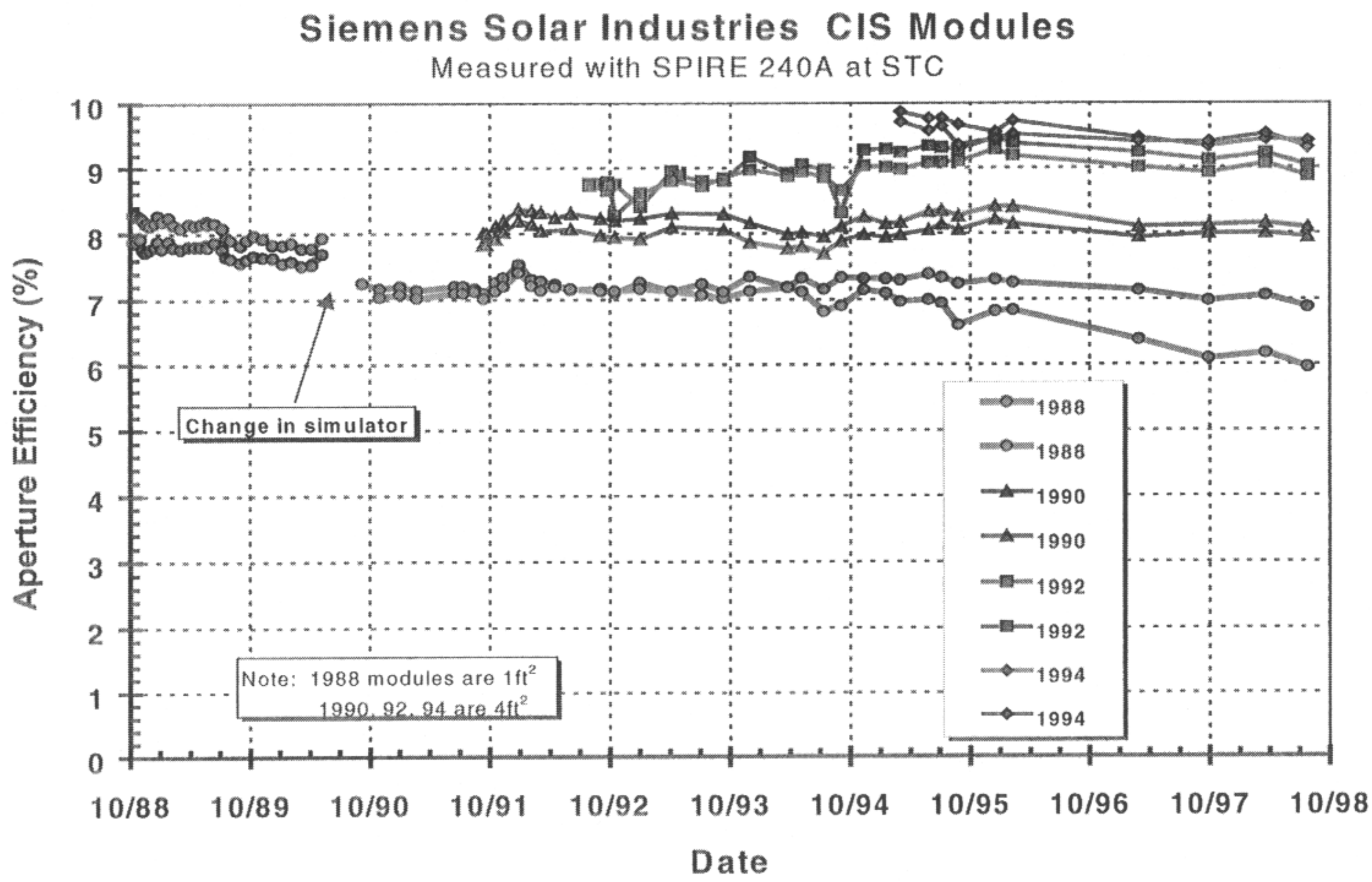
Field Performance

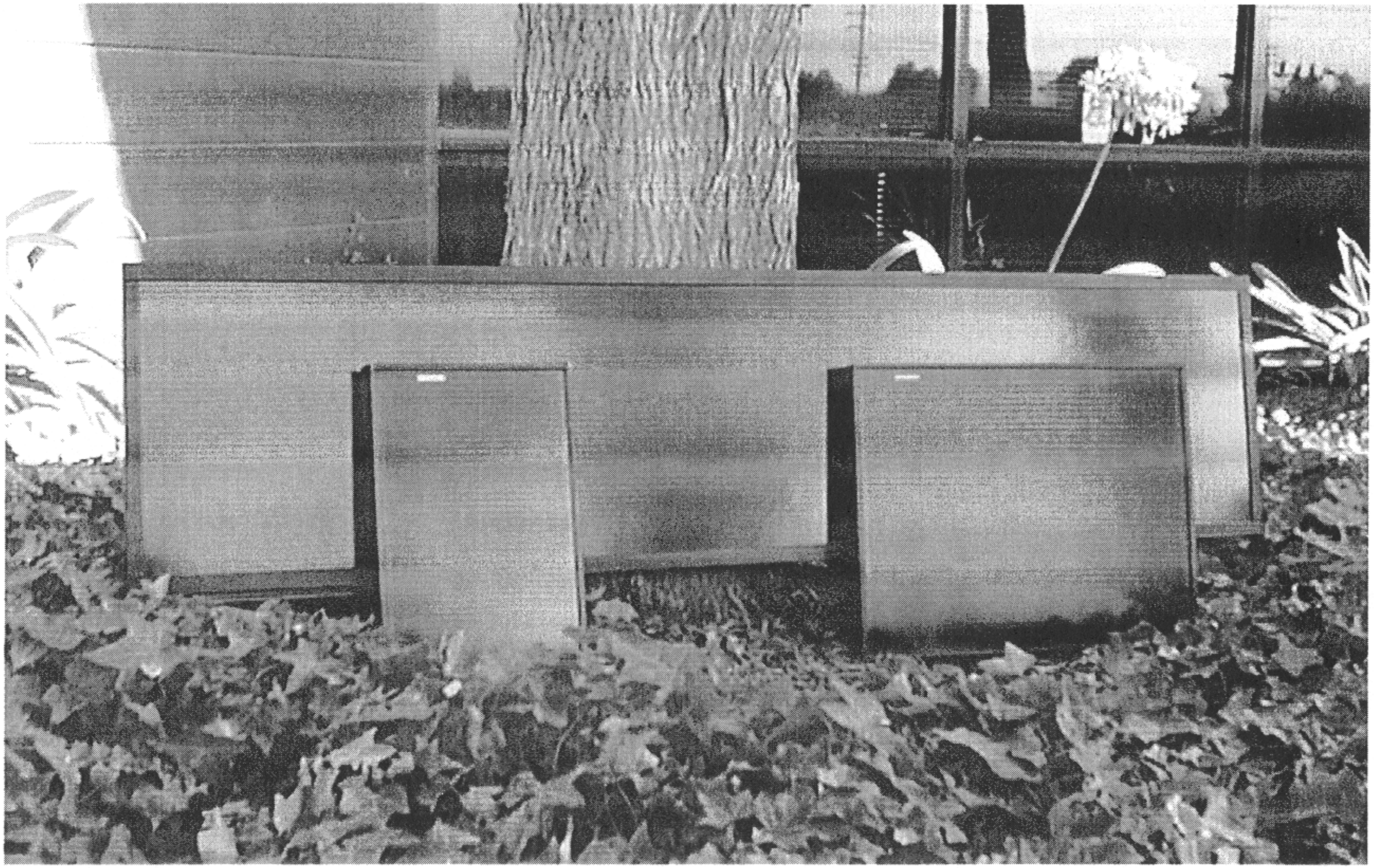


Outdoor exposure testing at NREL

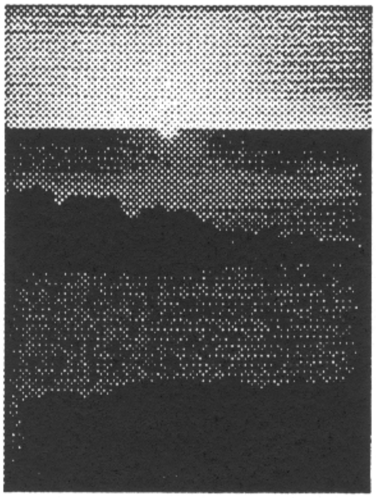


Conclusion

- CIS modules have shown excellent field stability.
- Large area module performance approaches the level of crystalline silicon based modules.
- Packages have demonstrated the ability to pass accelerated environment tests.
- Siemens is moving ahead, increasing CIS production and designing a module package that will be reliable for decades.



United Solar Systems



Module Reliability Testing
Results on
Standard and BIPV Products

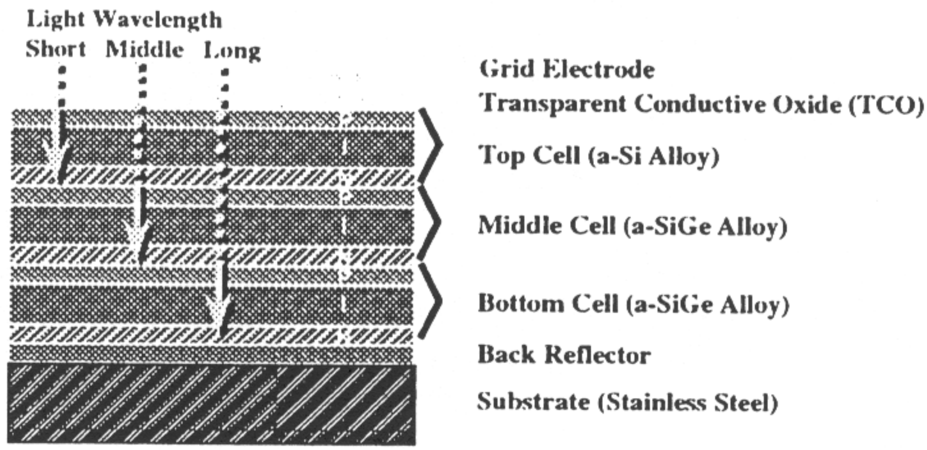
1998 PV Performance and
Reliability Workshop

November 3-5, 1998
Cocoa Beach, Florida

UNITED SOLAR SYSTEMS

- Advanced a-Si Triple-Junction PV Technology
- Roll-to-Roll Production Process
- Proven Flexible Lamination Design
- Complete Product Line
  - UNI-POWER PV Modules
  - UNI-SOLAR Flexible Solar Battery Chargers
  - UNI-PAC Portable Solar Chargers
  - UNIKIT Solar Lighting Systems
  - UNI-SOLAR *Roofing* Systems

TRIPLE-JUNCTION CELL STRUCTURE



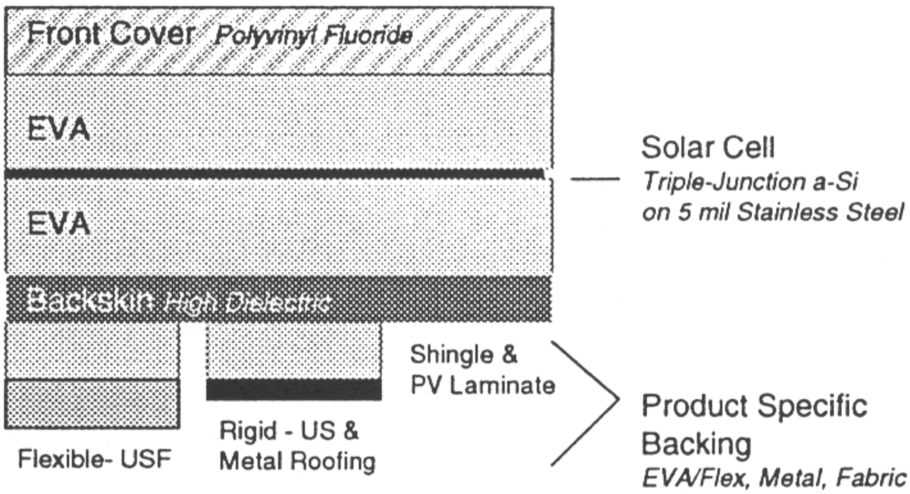
UNI-SOLAR

SOLAR CELL MATERIAL
(UNI-SOLAR Products Building Block)

- Triple-Junction a-Si Alloy Solar Cell
  - High Stable Efficiency
  - High Delivered Power and Energy / STC Ratios
  - Flexibility and Durability
- Laminate
  - Front Cover - Polyvinylfluoride
  - EVA
  - Redundant Interconnects & Bypass Diodes
  - EVA
  - Dielectric Backskin

UNI-SOLAR

UNI-SOLAR LAMINATE



UNITED SOLAR SYSTEMS ACHIEVEMENTS

- >10 Years Commercial Production of Multi-Junction, Amorphous Silicon Alloy (a-Si) Photovoltaic Products
- Record Setting Triple Junction Solar Cell, 14.6% Initial, 13% Stable Efficiencies
- Stabilized Module Efficiency of 10.4% for 1 ft^2
- Proven Product Development and Testing

UNI-SOLAR® PRODUCTS

- UNI-POWER PV Module
- UNI-SOLAR Flexible Battery Chargers
- UNI-PAC Portable Solar Chargers
- UNIKIT Solar Lighting Systems
- UNI-SOLAR *Roofing*

UNI-SOLAR

UNI-POWER PV MODULES

- Full Product Line - 64 Watts to 3 Watts
- Triple Junction Solar Cells
- Unbreakable (no glass)
- Anodized Aluminum Frame & Painted Galvalume Backing Plate
- Bypass Diodes
- UL Listed, IEEE 1262 & IEC 1646 Qualified

UNI-SOLAR

FLEXIBLE BATTERY CHARGERS

- Flexible, User-Portable Solar Charger
- Leading Solar Charger in Marine Market
- Three Sizes - 32, 11 and 5 Watt
- Soft-pack (vinyl and foam) packaging
- Bypass-Diodes Between Cells
- 10' Plug-in Wiring Harness to Battery
- UL Listed and 3 Year Limited Warranty

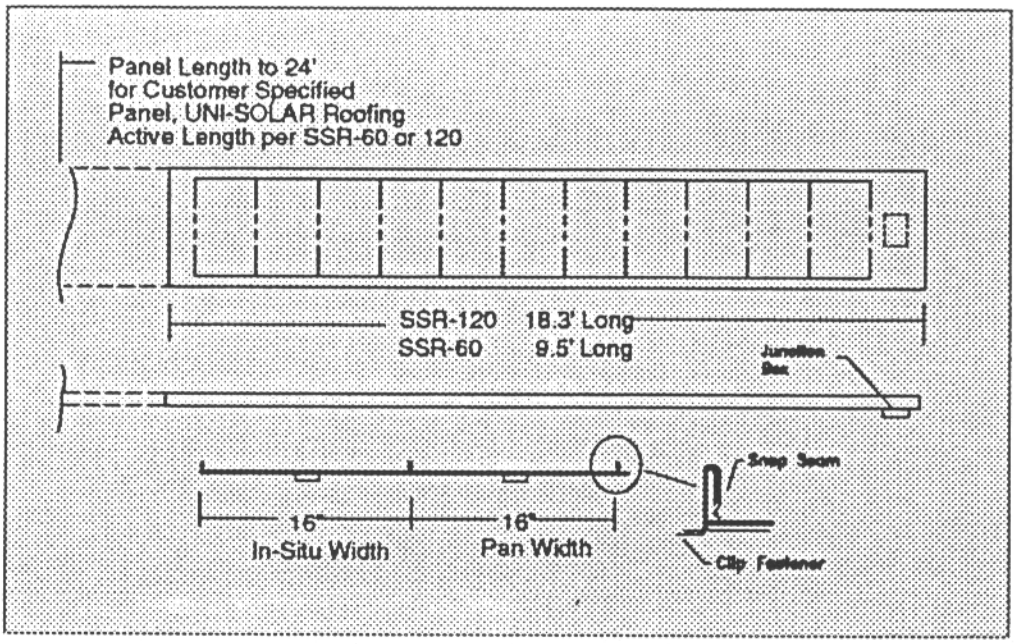
UNI-SOLAR

UNI-SOLAR Roofing

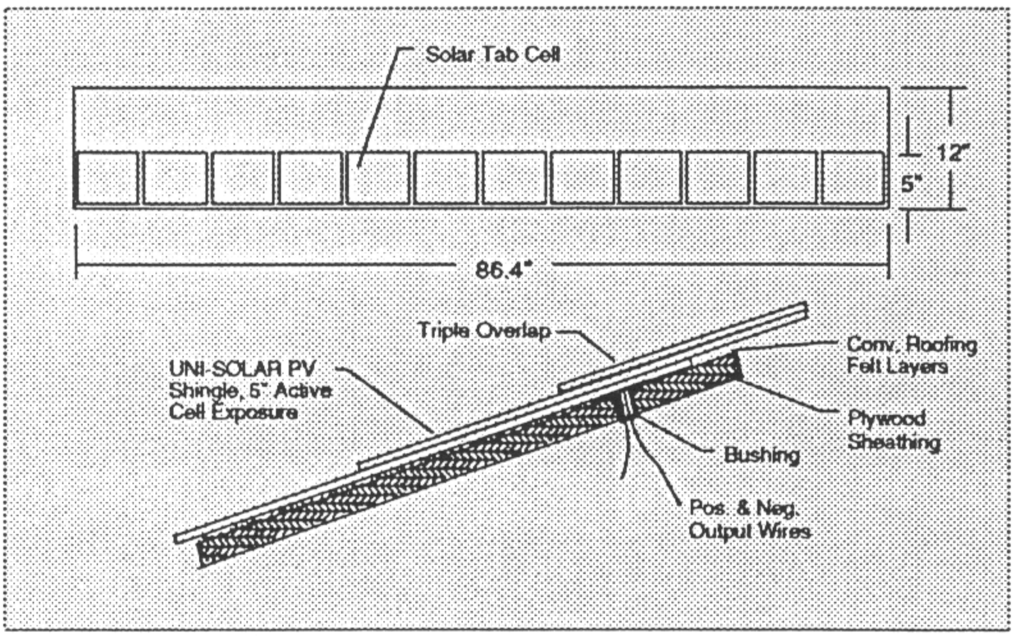
- Solar Electric Generator and Roofing Element
- Architectural or Structural Metal Roofing
  - 60 or 120 Watt, 9.5 or 18.3 feet long, 16" wide
  - UL Listed / IEEE Qualified
- Solar Electric Shingle
  - 15 or 17 watts, Approx. 7' wide, 5" exposure
  - Conventional Overlap Shingle Design
  - Beneath Deck wiring
  - UL Listed / IEEE Qualified

UNI-SOLAR

UNI-SOLAR SSR Panels



UNI-SOLAR SHR-15/17 Shingle



QUALIFICATION TESTING

- Approach
  - Generic Laminate Testing
    - Front Cover Independent Tests / UL Tests
  - Product In-House Testing
    - IEEE Testing on Components
    - Flexible Product Testing
    - Roofing Module Testing - Internal IEEE Test
  - Independent Lab Testing
    - UL / ASU-PTL / ISPRA / FM

UNI-SOLAR

TEFZEL ENCAPSULANT
Features and Benefits

- Solar Transparent
- Thin and Flexible
- Easier to Clean
- Shatterproof
- Light Weight

UNI-SOLAR

ADHESIVE-PHOTOCAP EVA
(Springborn Laboratories)

- Features and Benefits

  20 year service life
  (based on accelerated testing)

  High light transmission

  Excellent adhesion to silicon and
  aluminum

UNI-SOLAR

TEFZEL ENCAPSULANT
Test Results

- TEFZEL Outdoor Exposure Test

  Test conducted by DuPont

  Samples exposed for Over 15 years

  Retained 98% of original light transmission

  Maintained 85% of original elongation

  Maintained 93% of original tensile strength

UNI-SOLAR

ADHESIVE-PHOTOCAP EVA Test Results

- Outdoor Exposure at Phoenix, AZ Under 5 Suns for One Year
  - Standard-Cure EVA encapsulant with glass superstrate Resulted in a Large Yellowing Index* of 28.80
  - Standard-Cure EVA encapsulant with TEFZEL superstrate resulted in No Yellowing Index (0)

*Yellowing is visible at an index value of about 10

UNI-SOLAR

ADHESIVE-PHOTOCAP EVA Test Results

- 32 Weeks of Exposure Under Xenon-Arc Lamp at 100°C, >95% RH
  - Standard-Cure EVA Encapsulant with Glass Superstrate Resulted in a Large Yellowing Index of 72.0
  - Standard-Cure EVA Encapsulant with TEFZEL Superstrate Resulted in a Low Yellowing Index (<5)

UNI-SOLAR

UNITED SOLAR TESTING

- Based on IEEE and UL Standards and Covers All Key Tests, including:
  - Thermal Cycle, Humidity Freeze
  - Bypass Diode, Hot-Spot Endurance
  - Wet-Hi Pot, Salt-Fog
  - Flex Test (USF)
  - Performance
  - Mechanical Loading
  - Hail-Impact
  - Surface Cut
  - Strain Relief

UNI-SOLAR

QUAL. TESTING OF ROOFING

- IEEE-1262 & IEC 1646 Procedures and Specs
  - Structured for PV Modules/Thin Film PV Modules
- UL-1703 for Flat Plate Modules/Panels for Installation on or Integral with Buildings
  - Subject Full Size Modules to Fire Resistance Testing (UL-790)
- Environmental Testing Performed on Representative Modules due to Large Roofing Element Size
  - Retain All Key Features of Full Size Modules
- Use Existing Qualification of Metal Roofing
  - Uplift Resistance (UL-580)
  - Air/Water Infiltration ASTM E238 and ASTM E331-86

UNI-SOLAR

RELIABILITY TEST RESULTS

- Underwriter's Laboratory
  - April 15, 1998 UL Listing
    - US, USF and Roofing Products
      - PV Modules and Panels
      - Prepared Roof Covering - Shingles
- IEEE-1262 / IEC 1646
  - September 1, 1998
    - US, USF and Roofing Products
- ISPRA

UNI-SOLAR

Conclusions

- Diligent and Comprehensive Reliability Testing on Standard and Innovative Products
- Successful Product Design and Development
- Proven Commercial Experience
- High Customer Value

UNI-SOLAR

Reliability Testing of PV Modules at Solarex

By

John Wohlgemuth

What is Reliability Testing?

- Environmental testing that accelerates the stress associated with known environmental conditions or a known failure mechanism.
- Reliability testing must be guided by the results of outdoor testing.
- Stress levels must accelerate the same failure mechanisms observed in the field.
- Goal is to use the results of the tests to improve the module's ability to withstand the stress.

Qualification Testing

- A well defined set of accelerated environmental tests originally developed out of a reliability testing program.
- Incorporates strict pass/fail criteria.
- Used by customers to qualify modules for purchase.
- Used by manufacturers as a means of demonstrating a degree of reliability.

Limitations of Qualification Tests

- Stress levels are limited so give limited information about long term reliability.
- Stress levels are based on known field failure mechanisms so don't test for new mechanisms that may appear:
  - at longer exposure times,
  - with combinations of stresses, or
  - with new technologies.

Reliability testing at Solarex

- Much of it is based on accelerated tests from qualification sequence run for longer duration or in combination with other stresses.
- Continually performing failure analysis on returns and inspecting modules in the field to identify new failure mechanisms.

Thermal Cycle Tests

- Identifies failures associated with cracking of interconnect ribbons and fatigue of solder joints originally observed on substrate modules in 2 to 4 years of field exposure.
- Qualification sequence calls for 200 cycles of -40 to + 85 or 90 C with less than 5% (IEC-1215) or 10% (IEEE-1262) power loss.

Thermal Cycle beyond Qualification

- Not good to exceed temperature limits because you cause material failures that are not seen in the field.
- We have run samples well beyond 200 cycles - to over 1000 cycles.
- As long as we use a glass superstrate and thin interconnect ribbons there is no problem with the ribbons themselves.

Thermal Cycle beyond Qualification

- Power loss was not catastrophic, but a slow degradation in fill factor.
- Failure mechanism identified as fatigue in solder joints.
- Improved process control in soldering process minimizes fill factor loss.
- The standard qual test (200 cycles) is not long enough to see this effect.

A Case History

- Modules from a new piece of equipment were qualified though IEC-1215 including the 200 thermal cycles.
- Modules from this equipment were also subjected to outdoor testing.
- Outdoor testing indicated problems with the solder bonds from the new equipment.

A Case History (Cont.)

- Some of these modules were thermal cycled for an additional 400 cycles without any power degradation.
- However, outdoors these modules continued to experience problems.
- We duplicated the problem by running peak power current through the modules during thermal cycle tests.

Lessons Learned

- We now perform all thermal cycle tests with peak power current flowing through the module.
- We now do more reliability testing than just the qualification sequence when bringing new equipment or a new process on line.
- We now require well documented process monitoring for all proceeses and equipment.

Damp Heat

- Identified failure mechanisms include corrosion of metallization and adhesion bond failures.
- The Qualification Test calls for 1000 hours at 85% Relative humidity at 85 C.
- A well sealed package with reasonably corrosion resistant metallization can withstand at least 3000 or 4000 hours.

Damp Heat (Cont.)

- Significant power loss (> 5%) after 1000 hours usually indicates greater loss in longer term exposure.
- Failure is usually a steady decline in fill factor due to corrosion of contacts.
- Wet insulation resistance test after damp heat helps to find delaminations that are very difficult to see by visual inspection.

Damp Heat Limitations

- No source of electricity to drive corrosion.
- No thermal cycling to allow water to condense in the module.
- No method to assess bond strength unless there is a complete failure (a delamination).
- We are now working on developing modifications to the damp heat test to address these limitations for reliability not qualification testing.

High Voltage-Damp Heat

- Customer proposed to build a 2500 volt PV system.
- Performed damp heat test with 2500 volts between electric circuit of cells and grounded frame on module.
- At 85 C glass is quite conductive.
- Any conductive layer on glass will deplate in one polarity at this high a voltage.

UV/50TC/10HF Leg

- Qualification sequence includes 15 kWhr of UV, 50 thermal cycles from -40 to + 85 or 90C and 10 humidity freeze cycles from 85% relative humidity and 85 C to -40 C.
- UV test address UV weakening of adhesive bonds and UV degradation of materials.
- Thermal cycle and humidity freeze test strength of adhesive bonds.

UV/50TC/10HF Leg

- UV test is not long enough to see most material degradation, but in conjunction with the other 2 tests it is long enough to pick up delaminations from improperly primed surfaces.
- Test sequence is also good at identifying problems with the encapsulant curing process.
- It is useful as a reliability tool to repeat this test sequence several times or until failure with the same modules.

Developing Reliability Tests

- Long term UV-high temperature tests are best performed on small samples in Xenon or EMMA.
- Trying to develop an approach to combine damp heat with thermal cycling.
- Freezing is probably too severe after a long damp heat exposure.

Performance Criteria

- In the Qualification tests we use electrical performance, insulation resistance (dry and wet) and visual inspection.
- Need other measurement tools to determine what is happening in the modules.
- Adhesive bond pull strengths are useful. For example measure adhesion of encapsulant to glass before and after exposure.

Example

- Return from field exhibited a particular failure we had never seen before.
- While we suspected the damp climate, damp heat had never caused such a failure.
- Sample showed signs of the presence of liquid water.
- we place one end of the module in liquid water during the damp heat test.
- Result was similar to the field failure.

Reliability/Lifetime

- Frequently asked how long will today's modules last.
- Frequently asked how will today's modules fail.
- We really can't answer either of these questions although we can identify a number of potential failure mechanisms and provide estimates of their impact.

Lifetime of Today's Crystalline Modules Failure/Degradation Mechanisms

- EVA Browning - Under 1 sun conditions there should be no noticeable effect for about 50 years and then a slow reduction in optical transmission.
- Solder Bonds - Work damage due to thermal cycling results in slow degradation (less than 0.5% per year). Workmanship and process control issues could result in some early failures.
- Adhesive Bond Failures - Environmental stress slowly degrades chemical bonds.

Lifetime of Today's Crystalline Modules Failure/Degradation Mechanisms

- Corrosion -
  - Water penetration leads to corrosion of contacts, interconnects and solder bonds.
  - Corrosion of the input lead attachment system is one of the most likely early failure mechanisms.
  - Preventing the accumulation of liquid water is key to preventing corrosion.

Lifetime of Today's Thin Film Modules Failure/Degradation Mechanisms

- Corrosion very important since layers are so thin. Therefore it is very important to prevent adhesive failures in the package.
- Corrosion of output leads also critical because this is the easiest single point failure mode.
- Extremely important to track field performance and perform failure and degradation analysis.

Summary

- Reliability testing should be an ongoing process in coordination with process control, qualification testing and field testing.
- The longer we expect the products to last the more complex the reliability testing becomes.
- Combinations of accelerated stresses are required to duplicate some field failures.
- To understand ultimate product life we must test to failure.

ASU-PTL QUALIFICATION TEST EXPERIENCES

Bob Hammond
Director, Photovoltaic Testing Laboratory
Arizona State University EAST

1998 PV Performance & Reliability Workshop;
Nov. 3-5, '98, Cocoa Beach, FL.

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ACKNOWLEDGEMENTS

- SPONSORS: DOE, NREL, SNL, FSEC
- PTL CLIENTS
- PTL STAFF: Liang-Jun Ji, Todd Arends, Greg Gingell, Jeff Matland, Luis Petacci, Truitt Greenup
- KENT WHITFIELD

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PTL HISTORY

- Efforts began in 1992 to establish the PTL
- First qual test conducted in 1994 (UL 1703 - P)
- First full qual test was completed in 1996
- The PTL was Accredited by A2LA 6/23/97
- 52 Module types completed

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TECHNOLOGIES TESTED

- Flat Plate: c-Si, a-Si, CdTe

  per UL 1703, IEEE 1262, IEC 1215/1646
- Concentrator: HC Point Focus (HF only)
- IEEE P1513 tests are possible in 1999
- Test data are proprietary

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TEST RESULTS

- "Listed Products" (over 50 module types have passed qual tests -- see summary)
- Qual Test Failures (10 module types failed one or more tests (includes prototype modules) -- see summary)
- STR Outdoor Exposure Testing -- no measurable degradation

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"LISTED MODULES", 1.

UL & PMC makes the final determination of "pass/fail". Note 1. Listing Pending

Tests: P=partial; F=full Note 1: Listing Pending

MANUF.	MODEL	TECH.	TEST(S)	DATE
Amonix	3 plates	Conc, HC-PF	Humidity-Freeze	NA
ASE Americas	ASE50 ALF	FP, c-Si	P - UL1703	2/21/96
ASE Americas	ASE-DG-300-17	FP, c-Si	IEEE 1262/IEC 1215	8/31/98
ASE Americas	ASE-DG-300-50	FP, c-Si	IEEE 1262/IEC 1215	8/31/98
Astropower	AP1206	FP, c-Si	Damp Heat	10/23/95
Astropower	AP 1206	FP, c-Si	F - UL1703	May-96
Astropower	1206 - frameless	FP, c-Si	Hail Impact	7/12/96
Astropower	AP-90SF	FP, c-Si	P - UL1703	5/16/97
Astropower	6105	FP, c-Si	P - UL1703	6/18/98

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"LISTED MODULES", 2.

UL & PMC makes the final determination of "pass/fail". Note 1. Listing Pending

Tests: P=partial; F=full Note 1: Listing Pending

MANUF.	MODEL	TECH	TEST(S)	DATE
BP Solar	BP275	FP, c-Si	P - UL1703	7/7/97
BP Solar	BP590	FP, c-Si	P - UL1703	7/7/97
BP Solar	BP925L	CdTe	F - UL1703 [1]	10/2/98
EPV	EPV 30	FP, a-Si	F - UL1703	12/2/97
EPV	EPV 30	FP, a-Si	IEEE1262/IEC 1646	8/31/98
Evergreen	E-60	FP, c-Si	IEEE1262/IEC 1215	1/8/98
Evergreen	E-60	FP, c-Si	F - UL1703	1/8/98
Golden Photon	95187	CdTe	F - UL1703 [1], IEEE1262	7/12/96

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"LISTED MODULES", 3.

UL & PMC makes the final determination of "pass/fail". Note 1. Listing Pending

Tests: P=partial; F=full Note 1: Listing Pending

MANUF.	MODEL	TECH	TEST(S)	DATE
Kyocera	KC120-1	FP, c-Si	P - UL 1703	12/11/97
Kyocera	KC80	FP, c-Si	P - UL 1703	12/11/97
Kyocera	KC60	FP, c-Si	P - UL 1703	12/11/97
MSEC	Ra-220?	FP, c-Si	UL 1703 Hot Spot	1994
RES	SS1942MF	FP, c-Si	ASTM E1036 (IV)	Apr-97
SBS	Custom	FP, c-Si	ASTM E1036 (IV)	1/4/95
SBS	Custom	FP, c-Si	ASTM E1036 (IV)	12/20/96
SBS	Custom	FP, c-Si	ASTM E1036 (IV)	5/16/97
SBS	Sunslate/SSI	FP, c-Si	F - UL 1703 [1]	8/19/97
SBS	Sunslate/SX	FP, c-Si	ASTM E1036 (IV)	12/2/97
SBS	Sunslate/various	FP, c-Si	ASTM E1036 (IV)	5/11/98
SBS	Sunslate/SX/AST	FP, c-Si	P - UL 1703 [1]	5/18/98

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"LISTED MODULES", 4.

UL & PMC makes the final determination of "pass/fail". Note 1. Listing Pending

Tests: P=partial; F=full Note 1: Listing Pending

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Siemens	Pro 4 JF M75S	FP, c-Si	Dynamic Load	2/13/95
Siemens	PC 4 JF	FP, c-Si	Hail Impact	5/15/95
Siemens	PC 4 JF	FP, c-Si	Dynamic Load	5/25/95
Siemens	SM110	FP, c-Si	P - UL 1703	2/25/97
Siemens	SR50-Z	FP, c-Si	IEEE 1262	1/8/98
Siemens	M55	FP, c-Si	Dynamic load/Hail Impact	7/1/96
Solarex	MSX-240	FP, c-Si	IEC 1215	9/30/96
Solarex	MSX 120	FP, c-Si	dynamic load	12/3/96
Solarex	MSX 240	FP, c-Si	P - UL 1703	2/25/97
Solarex	MSX-120	FP, c-Si	PMC [1] (1262-1215)	6/30/98

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"LISTED MODULES", 5.

UL & PMC makes the final determination of "pass/fail". Note 1. Listing Pending

Tests: P=partial; F=full Note 1: Listing Pending

MANUF.	MODEL	TYPE	[illegible]	DATE
Solec	SQ-80	FP, c-Si	P - UL 1703	2/12/96
Solec	S-100D	FP, c-Si	P - UL 1703	12/3/96
Solec	S-055	FP, c-Si	P - UL 1703	12/3/96
Solec	S-110D	FP, c-Si	P - UL 1703	8/12/98
STR	AP-6105	FP, c-Si	P - IEEE 1262	4/9/97
STR	ASE-50-AL/17	FP, c-Si	P - IEEE 1262	4/9/97
STR	DV50-SS	FP, c-Si	P - IEEE 1262	4/9/97
STR	S-55	FP, c-Si	P - IEEE 1262	4/9/97
STR	M55	FP, c-Si	P - IEEE 1262	4/9/97
STR	MSX 64	FP, c-Si	P - IEEE 1262	4/9/97

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"LISTED MODULES", 6.

UL & PMC makes the final determination of "pass/fail". Note 1. Listing Pending

Tests: P=partial; F=full Note 1: Listing Pending

MANUF.	MODEL	TECH.	TEST(S)	DATE
Syner-Tech	prototype	FP, c-Si	ASTM E1036 (IV)	12/16/97
USSC	US-64	FP, a-Si	P - UL 1703	3/17/97
USSC	SHR-17	FP, a-Si	P - UL 1703	10/27/97
USSC	SSR-128	FP, a-Si	P - UL 1703	10/27/97
USSC	ALL	FP, a-Si	PMC [1] (1262-1646)	10/1/98

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SUMMARY OF PV MODULE QUALIFICATION TEST FAILURES: #1

Based on 21 Full Qualification Tests (190 modules) and 42 Partial Qualification Tests (126 Modules); Total module types: 5Results of prototype tests are not included

TEST FAILED	TEST SPEC	TEST	Failures [1] #	Failures [1] %	POSSIBLE REASON FOR FAILURE
Electrical Performance	UL	as received	2	4%	cells efficiency below specifications
	IEC	85/85	2	4%	moisture ingression; delamination
Wet Hi-Pot	IEC, IEEE	as received	1	2%	back skin too thin; pin holes in back skin; edge-seal
		85/85	1	2%	path length too short; poor workmanship
		HF10	1	2%	
Dry Hi-Pot	UL	HF10	2	4%	edge-seal path length too short; poor workmanship

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ASU PTL QUALIFICATION TEST EXPERIENCE

SUMMARY OF PV MODULE QUALIFICATION TEST FAILURES: #2

By-Pass Diode	IEC, IEEE		1	2%	incorrect diode rating
			1	2%	shorted connection (J-box burn)
J-Box Pulling	UL		1	2%	inadequate adhesive
Strain Relief	IEEE, UL		2	4%	poor design or workmanship
Inverse Current Overload	UL		1	2%	series fuse rating too high
Dynamic load	IEC, IEEE		1	2%	broken cell interconnect
Static load	IEC, IEEE, UL		1	2%	panel separated from the frame
Visual (J-Box Deformed)	IEC, IEEE, UL	TC200	1	2%	improper plastic materials
TOTAL MODULE TYPES THAT FAILED [2]			10	19%	

Note 1: Failure percentages are based on the total number of module types (52)

Note 2: Total is not equal to the sum of the failures: some module types failed more than one test.

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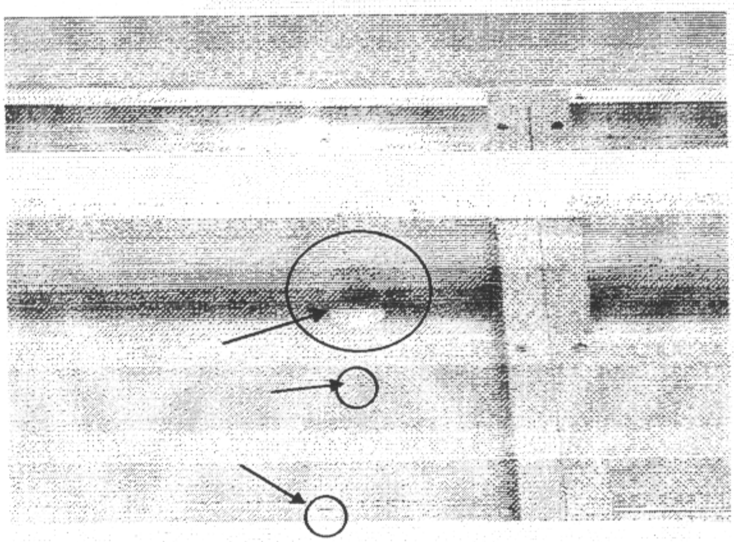
STR MODULE #8; BLISTER



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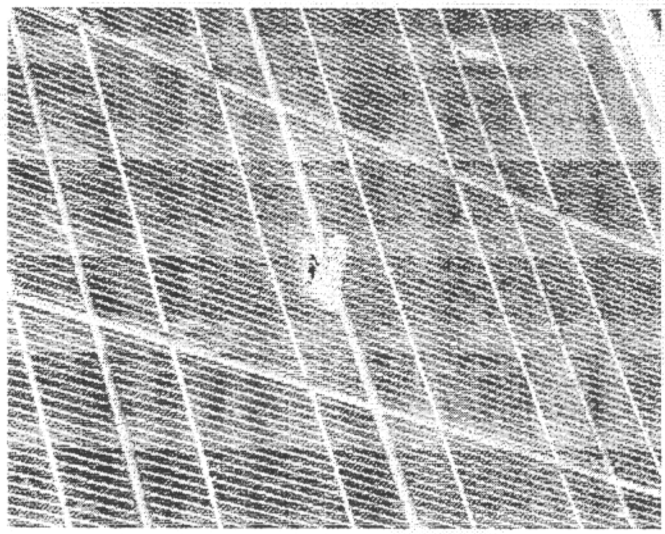
STR #M31: BULLET HOLE?



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PTL COST STRUCTURE

TEST STANDARDS / PROGRAMS	$<0.8m^2$	$0.8\text{-}2.4m^2$
PMC (IEEE 1262 & IEC 1215 & PV-3) (c-Si)	$22,500	$27,125
PMC (IEEE 1262 & IEC 1646 & PV-3) (a-Si)	$26,179	$31,492
IEC 1215	$21,333	$26,670
IEEE 1262 (c-Si)	FREE WITH IEC 1215	
IEC 1646	$25,012	$31,037
IEEE 1262 (a-Si)	FREE WITH IEC 1646	
UL 1703 concurrently with any of the above	$6,890	$7,890
UL 1703	$13,207	$16,278
IEC 1215, IEEE 1262, UL1703	$28,223	$34,560
IEC 1646, IEEE 1262, UL 1703	$31,902	$38,927

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COST OF QUAL TESTING

- In addition to PTL fees, UL and PMC each charge a fee (application, audit, and licensing fees) for their programs.
- UL and PMC programs begin with an application to those organizations by the manufacturer; the PTL cannot begin testing without UL and/or PMC approval.

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CONCLUSIONS

- Qual tests DO identify weak areas in product design
- There is value in prototype testing
- Qual test costs can be reduced if UL, IEEE, and IEC test are "harmonized"

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FOR ADDITIONAL INFORMATION

- E-mail: ptl@asu.edu
- Voice: 602-727-1220
- Fax: 602-727-1223

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Q&A INDEX

- Q&A 1. What is the value of PMC to us (e.g., the manufacturer)?
- Q&A 2. What is the difference between UL 1703, IEEE 1262, IEC 1215, IEC 1646, & PMC?
- Q&A 3. What is a multi-client testing program?
- Q&A 4. What is the cost if we want to have 6 modules (of the same type) tested.
- Q&A 5. Where can I get test standards?
- Q&A 6. RECIPROCITY: Does the PTL have Reciprocity with ESTI - Ispra?
- Q&A 7. What are the "Guidelines for Retest Requirements" and "Qualification by Similarity"?
- Q&A 8. What are the differences in the tests between UL1703, IEEE 1262, and IEC 1215?

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PV:BONUS 2

November 3, 1998

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1998 National Center for Photovoltaics
Photovoltaics Performance and Reliability Workshop
Cocoa Beach, Florida

Reliability Issues of a Combined PV/Thermal Collector

Joe McCabe, P.E.
Solar Design Associates, Inc.

Solar Design Associates, Inc.

History:

- Then: Late 70's and early 80's attempts to combine crystalline silicon PV and solar thermal harvest.
  Did not achieve commercialization due to:
  Loss of electrical power production at higher temperatures (losses of more than 5% per 10 degrees C), high costs and lack of appreciation of potential.

- Now: Amorphous silicon (a-Si) alloy solar cells exhibit reversible, light-induced changes in their properties (Staebler-Wronski). Original a-Si products had large power output degradation. Today's have high stabilized efficiencies with ~2% per 10 degrees C losses.

- Today's a-Si cells offer low costs and high-reliability

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Why PV/T?

Economics….~75-80% of the standard PV (only) system's installation cost are covered in the PV/T installation including:

- Sales and marketing costs
- Field logistics
- Scheduling and supervision
- Warehousing
- Packaging
- Shipping and handling
- Roof preparation
- Mounting hardware
- Installation labor and the overhead for the crew
- Costs to install the thermal only portion

Only other costs are the PV electrical connection which can be 120 VAC from micro inverter.

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Other Less Quantifiable, but High-value Benefits:

- Reduction in aperture area
- More flexibility = more installations
- The 'sex appeal' and simple elegance of an integrated dual-function device
- Vastly improved aesthetic results achieved with full integration and smaller array areas
- PV/T has the potential to enliven both the solar thermal *and* PV markets

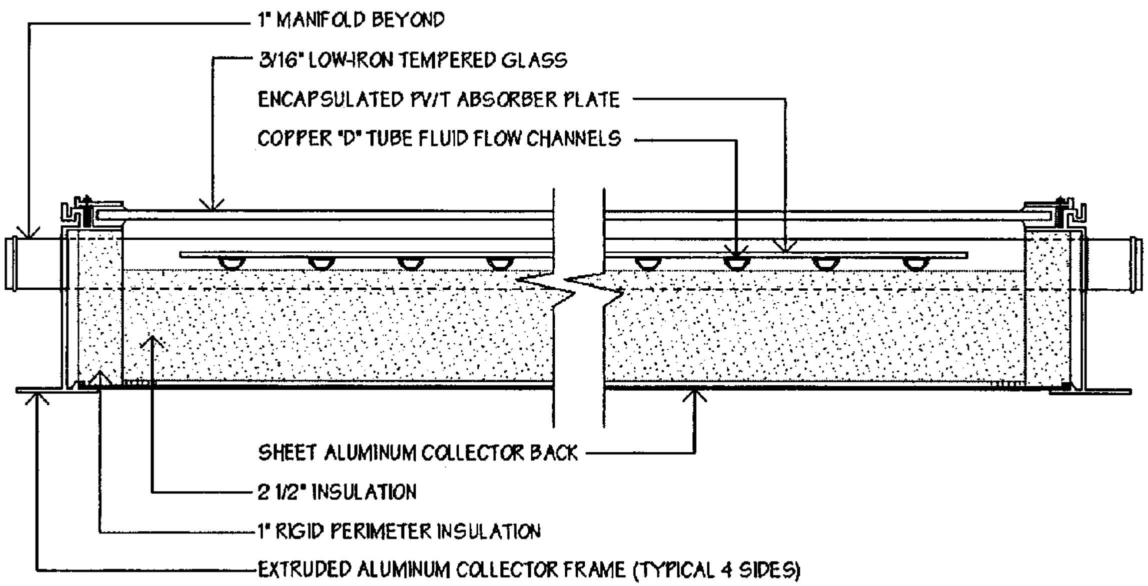
Embodied Energy:

- Some PV's take 5 years to generate the power needed to make the modules.

- Much of this is embedded in the encapsulant, and framing.

- PV/T uses a-Si technology with ~.5 years return on energy for the PV cells.

Schematic Diagram of PV/T Product



Cross section of proposed hybrid PV/T collector

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Some Reliability Issues with Standard PV:

- Delamination
- Browning of EVA
- Reduced wire insulation resistance
- Power Loss
- Visual Defects
- Bypass diodes failure
- Tedlar damage

Additional Reliability Issues Specific to PV/T:

- **High stagnation temperatures.**
- **High quality riser tube to headers connections. (Static Pressure Testing).**
- **Expansion and contraction effects on cell interconnections wiring.**
- **Expansion and contraction mismatch of thermally conducting materials (Thermal shock / water spray tests, and cold fill tests).**
- **Bypass diodes for miss match, shading, damaged cells. High temperature environments require special attention to placement and sizing of diodes (Bypass diodes to not effect power outputs, and are an added advantage to collectors reliability and operation).**
- **Wiring connections, junction boxes, for electrical transmission.**

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The PV/T product must satisfy these Standards and Codes:

- UL (1703)
- IEEE (1262)
- IEC (1646)
- NEC (690)
- ASHRAE (Thermal Performance Test 93-1986)
- Solar Rating and Certification Corporation

Conclusion

- PV/T Product Has Significant Advantages Over Conventional Side-By-Side PV and Thermal Systems
- PV/T Product has Wide Market Potential
- Important Technical and Reliability Issues Must be Met
- Technical Solutions Have Been Identified and Being Addressed

Testing *for BIPV*

By

John Wohlgemuth

Solarex

BIPV Requirements

- Must work as module.
- Must work as structural component of building.
- Must be a safe electrical system.
- Must be a safe mechanical system.
- As an integral part of a building the module must be reliable and have a long lifetime.

Testing Requirements as a PV Module

- Qualification: IEC 61215 or 61646 and IEEE 1262. (may be modified if all exposures are not expected)
- Safety: UL 1703 and the new IEC 61730 when completed.
- Reliability: Similar to standard PV modules, but with considerations of its intended use.

IEC 61730 - Additional Tests for BIPV Applications

- Surge impulse voltage stress test
- Partial discharge test
- Fire test
- Glass impact test

Modifying module tests

- Understanding the building construction and operating details is the first step in modifying the module test protocol.
- If the back of the module is going to be inside the conditioned space then test it that way.
- Don't require vertical walls to pass snow loading.
- Conversely BIPV modules are likely to run even hotter than normal because of the building insulation behind them, so test accordingly.

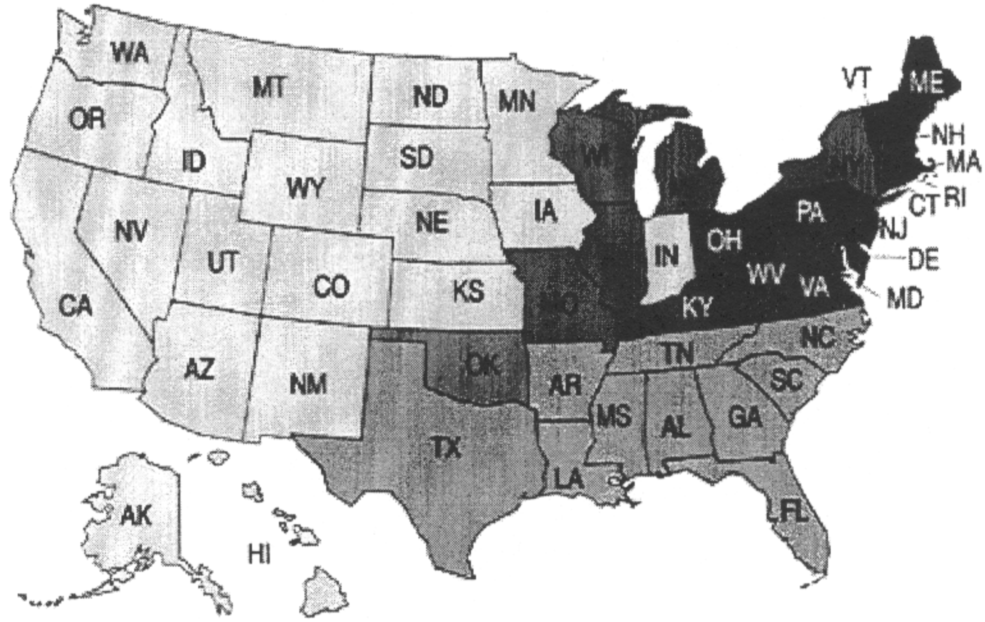
Testing Requirements as a Building Component

- In accordance with Building codes, which are not standard or uniform around the country.
- Safety - For example ANSI Z97.1 for glass breakage. These tests depend upon how the product is used/deployed.
- Accelerated environmental tests depending on the intended usage.

Building Codes (Examples)

- UBC - Uniform Building Code
- BOCA - Building Officials and Code Administrators
- CABO - Council of American Building Officials
- ICBO - International Conference of Building Officials
- SBCCI - Southern Building Code Congress International
- ICC - International Code Council

Know Your Code!



Current Areas of Building Code Use

ICBO's *Uniform Building Code™*

ICBO's *Uniform Building Code™* and/or **SBCCI's** *Standard (Southern) Building Code™*

SBCCI's *Standard (Southern) Building Code™*

SBCCI's *Standard (Southern) Building Code™* and/or **BOCA's** *National Building Code™*

ICBO's *Uniform Building Code™* and/or **BOCA's** *National Building Code™*

BOCA's *National Building Code™*

State Code

CONSTRUCTION BOOK EXPRESS

Building Codes ?

- There are also numerous local codes like the South Florida Building Code for Dade County, affectionately called the "Hurricane Code". This calls out the requirement to provide a specified resistance to a 2 by 4 timber shot from a cannon.
- In any location you must contact the local building officials to determine which code(s) apply.

Tests Methods for Buildings

- ASTM publishes a 4 volume collection called "Standards in Building Codes" that includes 1300 specifications and test methods.
- Many of these may be applicable to PV modules when used in a particular BIPV applications.

Selected ASTM Tests

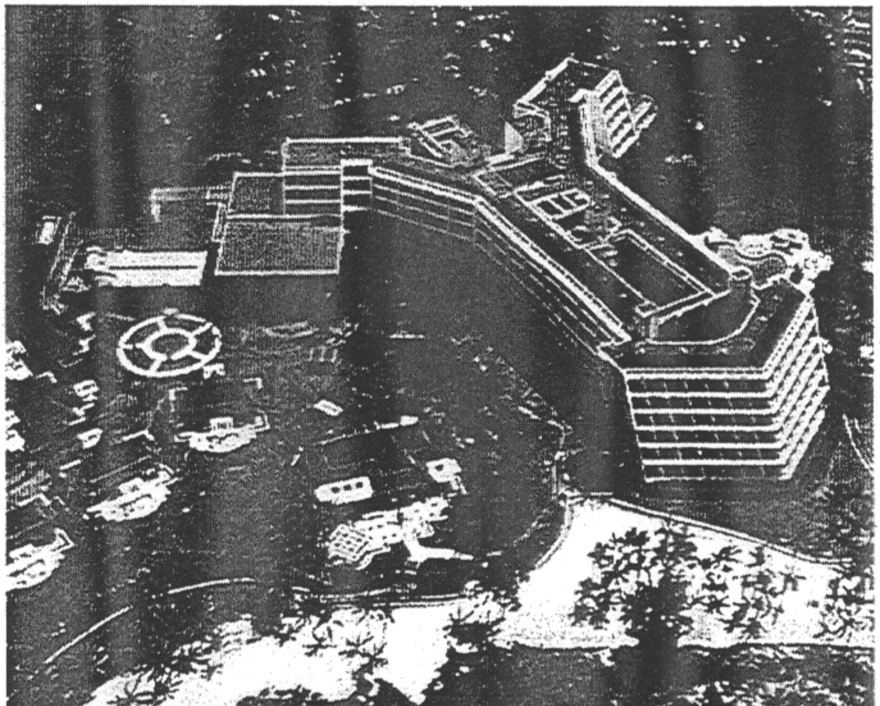
- ASTM E283 - Test Method for determining the rate of air leakage through windows and doors.
- ASTM E330 - Test for structural performance of exterior windows and doors by static air pressure difference.
- ASTM B331 - Test for water penetration of exterior windows and doors by uniform static air pressure difference.
- ASTM B117 - Standard method of salt spray (fog) testing.
- ASTM E1425 - Practice for determining the acoustical rating of windows and doors.

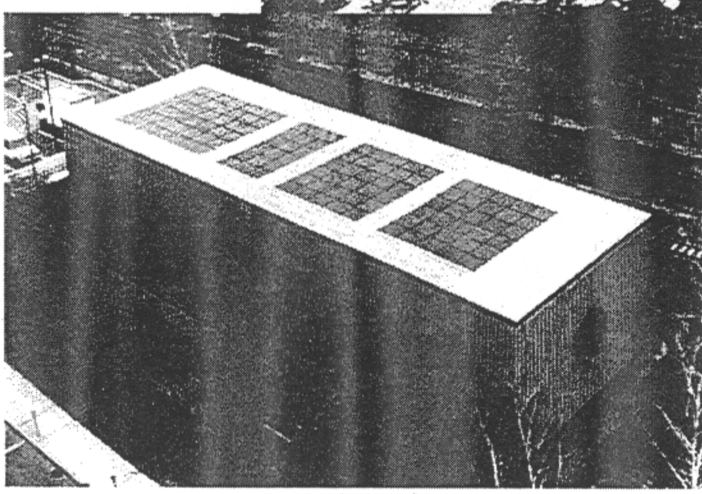
Summary

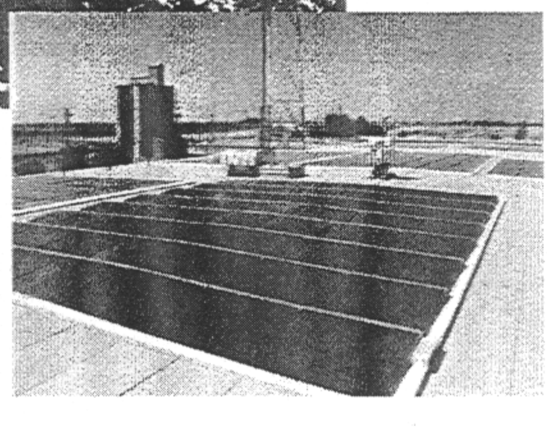
- The building industry is to a large extent a custom industry.
- BIPV is a custom product.
- For now each project will require a degree of engineering/design as well as a different set of tests to be conducted in order to demonstrate that the modules meet the applicable codes and standards.

PowerLight
Corporation

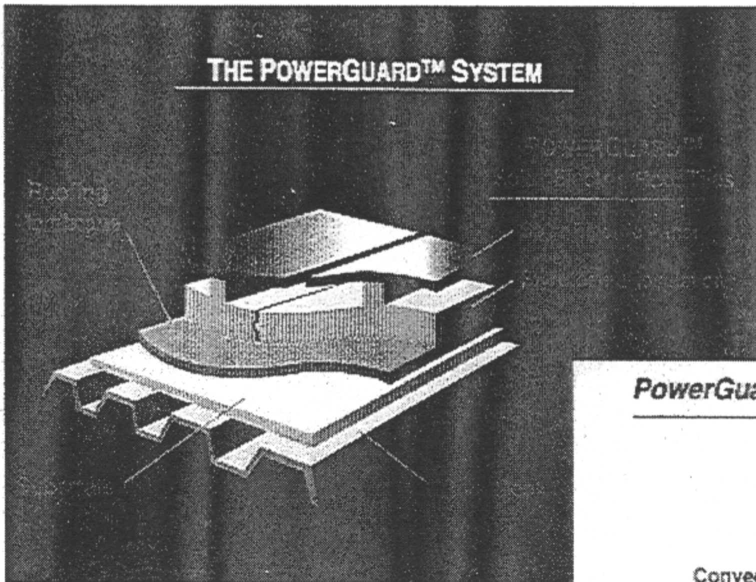
Monitoring for Long-Term Durability of PV Systems / Case Study: PowerGuard

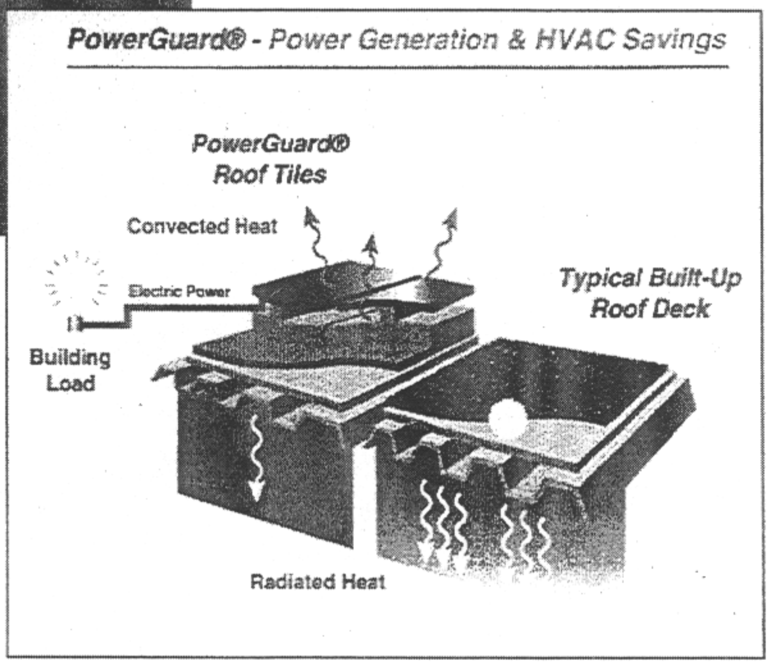




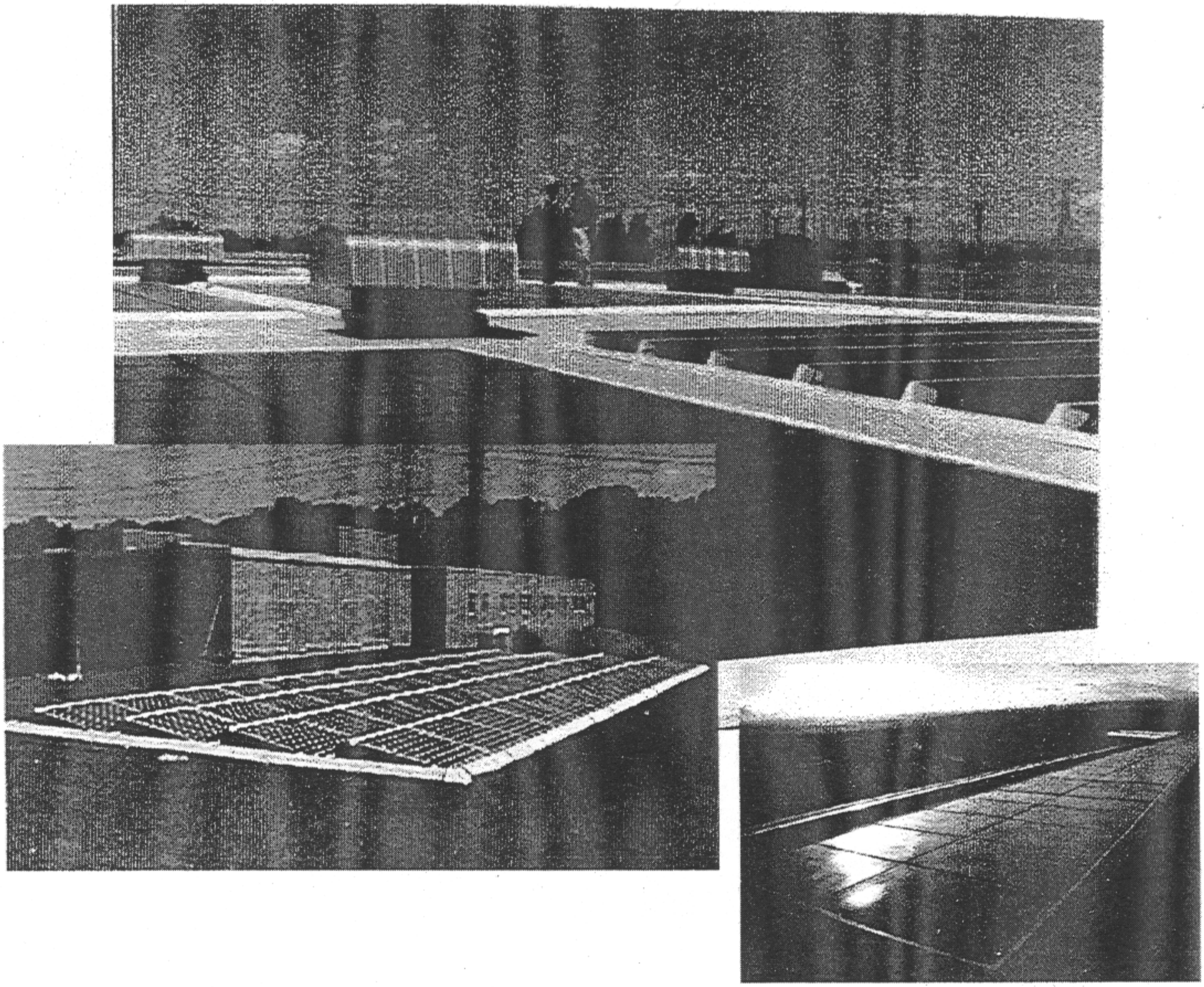


PowerGuard Roofing Tile





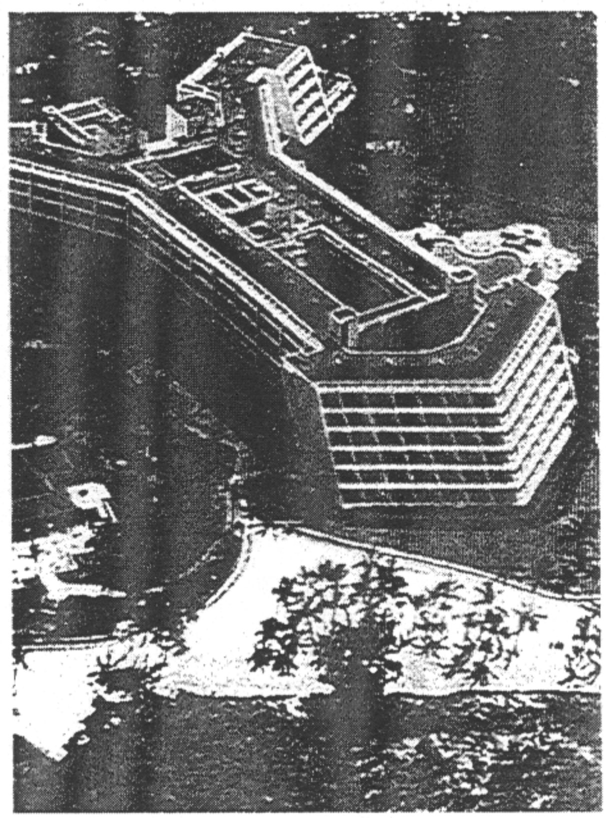
PowerGuard System



Monitoring PowerGuard Systems

Case Study: 75 kW PowerGuard System Mauna Lani Bay Hotel

1. *Documentation:*
   Characterize System as Installed
   - Manufacturing QA/QC
   - Installation Inspection
     - Physical Condition
     - Electrical Performance
     - Thermal Performance

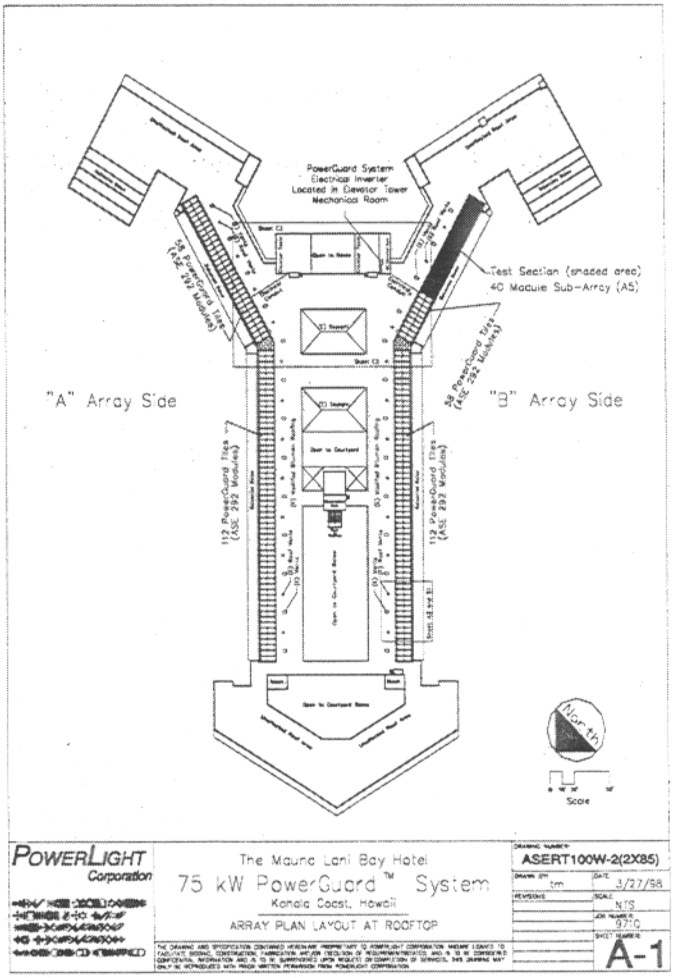


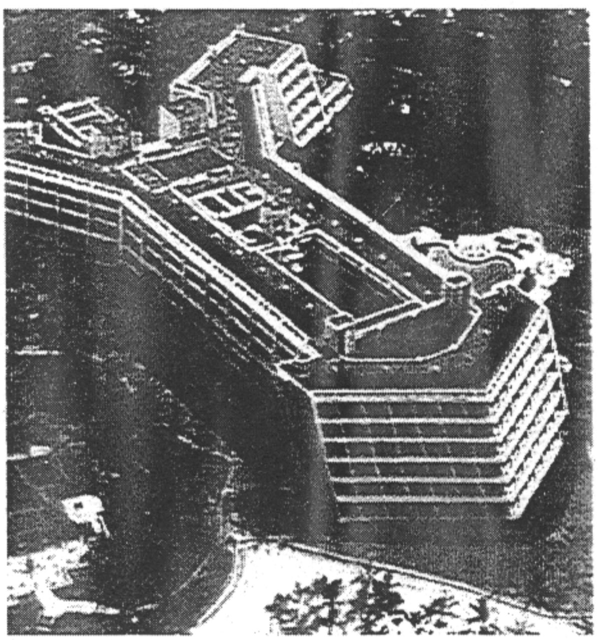
2. *Long-Term Monitoring*
   - Routine Inspection
   - DAS
   - Ongoing Research

Documentation

Installation Inspection

- For large (>30 kW) systems, designate "test section" for detailed component documentation.
- Characterize physical condition, electrical and thermal performance of entire system.

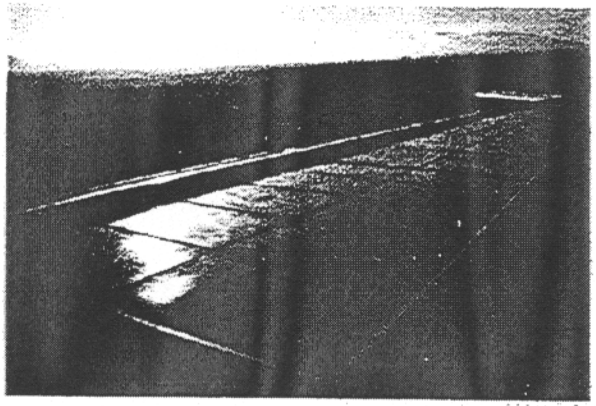




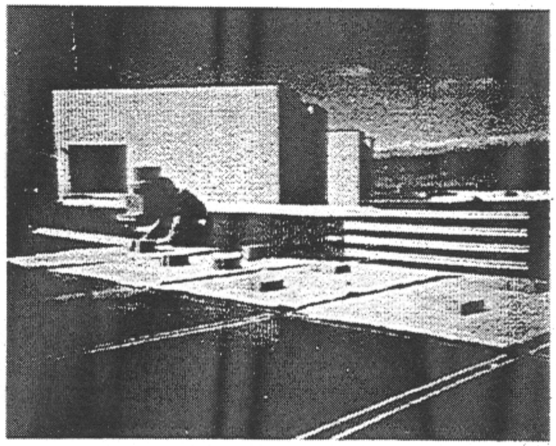
Documentation

Installation Inspection: Physical Condition of System

- SystemComponents
  - PV Laminate
  - Tile Materials
  - Tile Interconnection
  - Electrical Connectors/Wiring
  - Array Junction Boxes
  - Inverter
  - DAS
  - Roof Condition
  - Curb



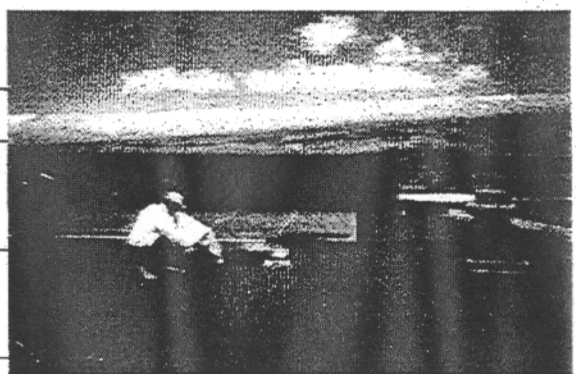
- Test Section-Detailed Inspection
  - Tongue and groove gaps
  - Tile dimensions
  - Tile coating
  - PV encapsulant / cell condition
  - Pull tests on field samples
  - Quick connects
  - IR imaging
  - I/V curves
  - Sheet metal screws in curb

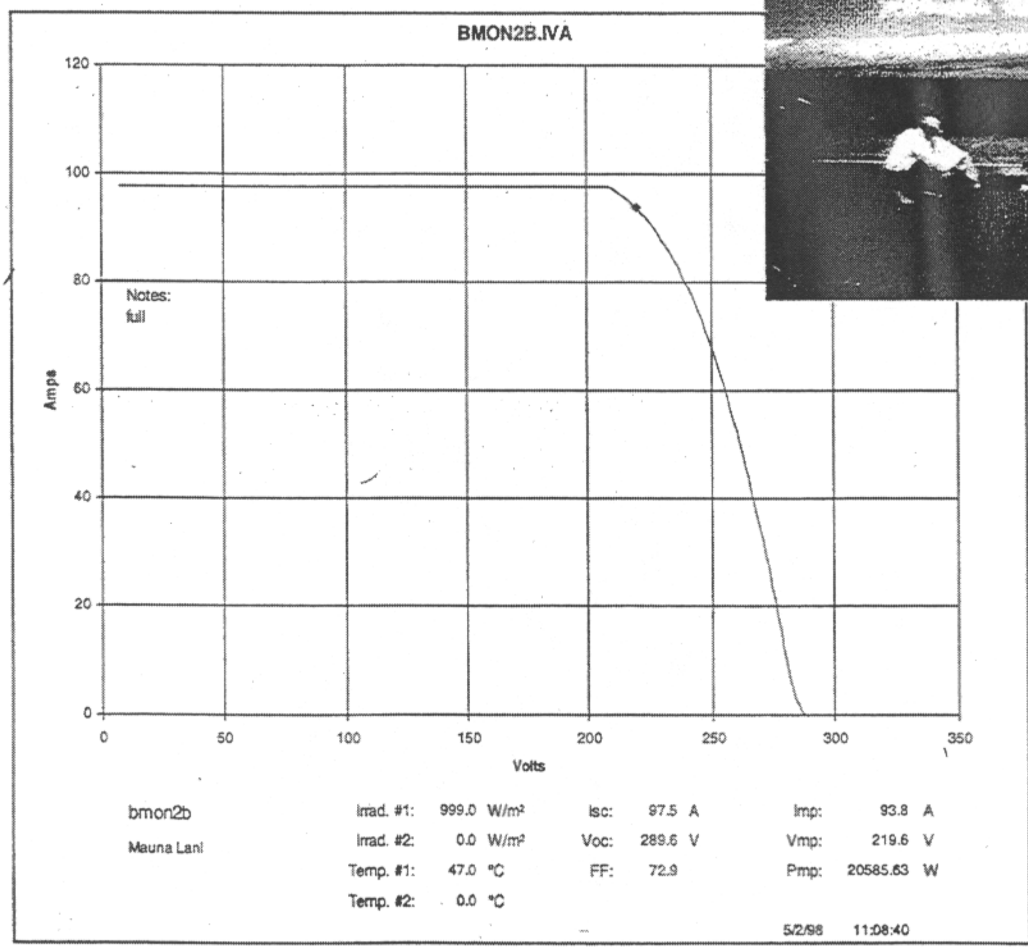


Documentation

Installation Inspection: Electrical Characterization of System

- Check Voc of each string during installation
- I/V Curves (if possible)
  - Test Section-Individual Laminates
  - Entire System-Strings / Sub-Arrays / Array
- Inverter
- AC / DC Output Monitored by DAS

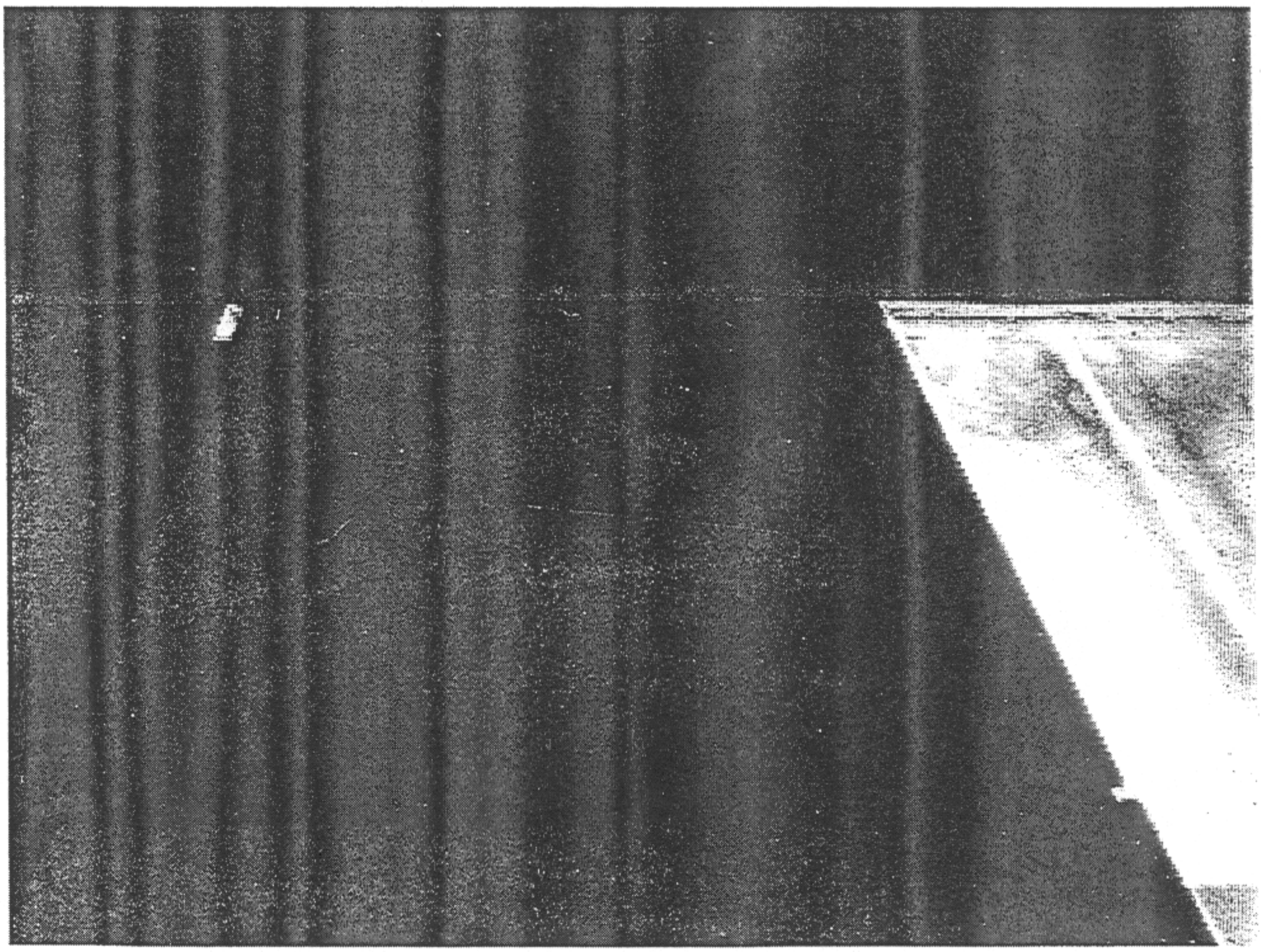




Documentation

Installation Inspection: Thermal Characterization of System

- IR Imaging (if possible)
  - Array in Short-Circuit Condition
  - Array in Normal Operating Conditions
  - Electrical Wiring
- Array Temperature Data
  - Tile temperatures monitored via DAS

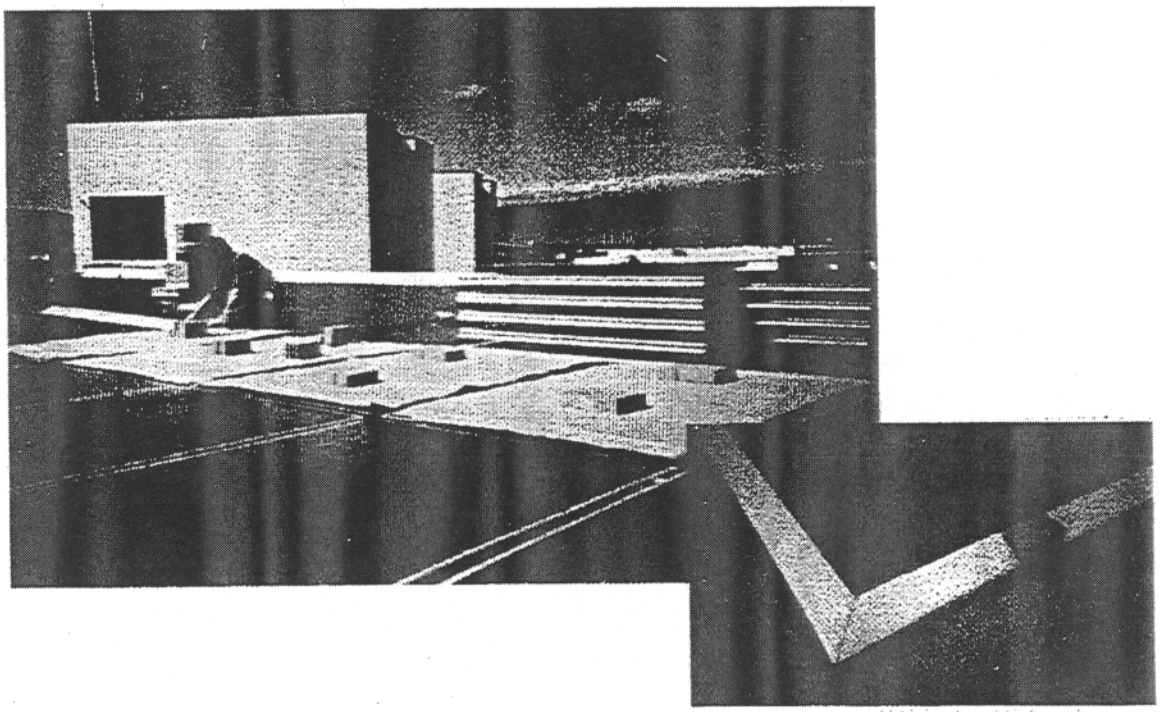


Long-Term Monitoring

Semi-Annual System Inspection

Semi-Annual Inspection of Test Section

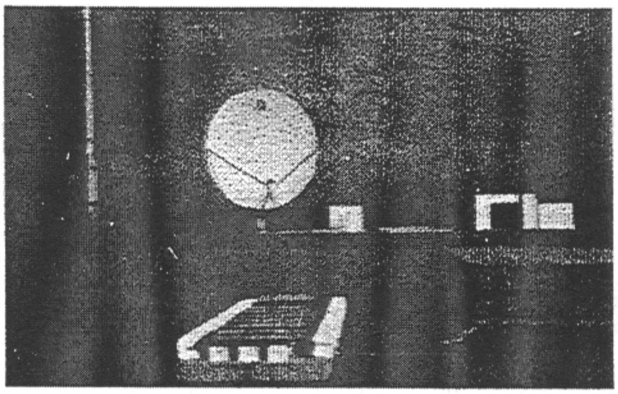
- Tongue and groove gaps
- Tile dimensions
- Tile coating
- PV encapsulant / cell condition
- Pull tests on field samples (every 2 years)
- Quick connects
- IR imaging
- I/V curves
- Sheet metal screws in curb

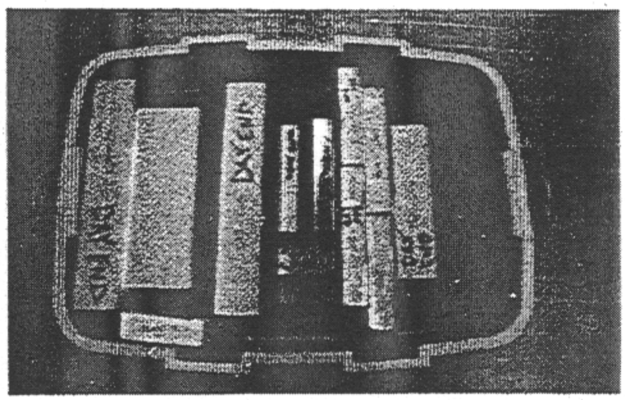


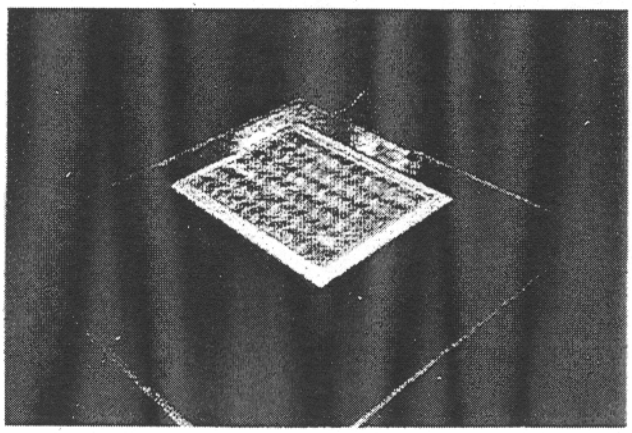
Long-Term Monitoring

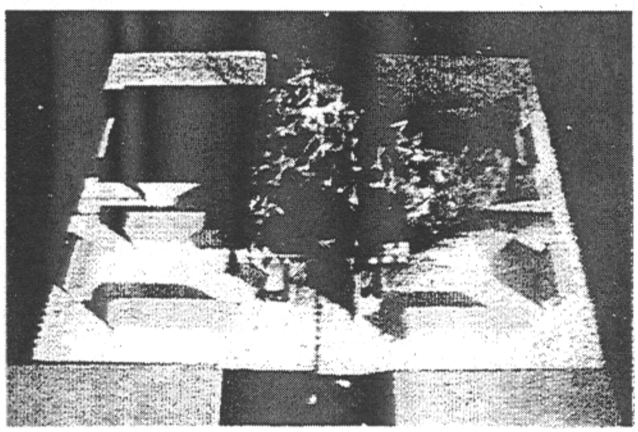
Ongoing Research

- Library of materials kept as control samples
- Wind-Tunnel Testing
- Coating Testing
- Fire Rating Tests
- Electrical Connector Testing









Durability Testing of Electrochromic Window Glazings

N.L. Sbar, L.A. Michalski, H.N. Volltrauer,
T.D. Ngo, G.J. McComiskey

SAGE Electrochromics, Inc.
2150 Airport Drive, Faribault, Minn. 55021
Phone 507-333-0078
Fax 507 333-0145

**SAGE Electrochromics, Inc. thanks
A. Czanderna, D. Benson, E. Tracy, and J-G Zhang
of the National Renewable Energy Laboratory (NREL)
Electrochromics Team for high temperature testing
of SAGE devices in their XR260 solar simulator.**

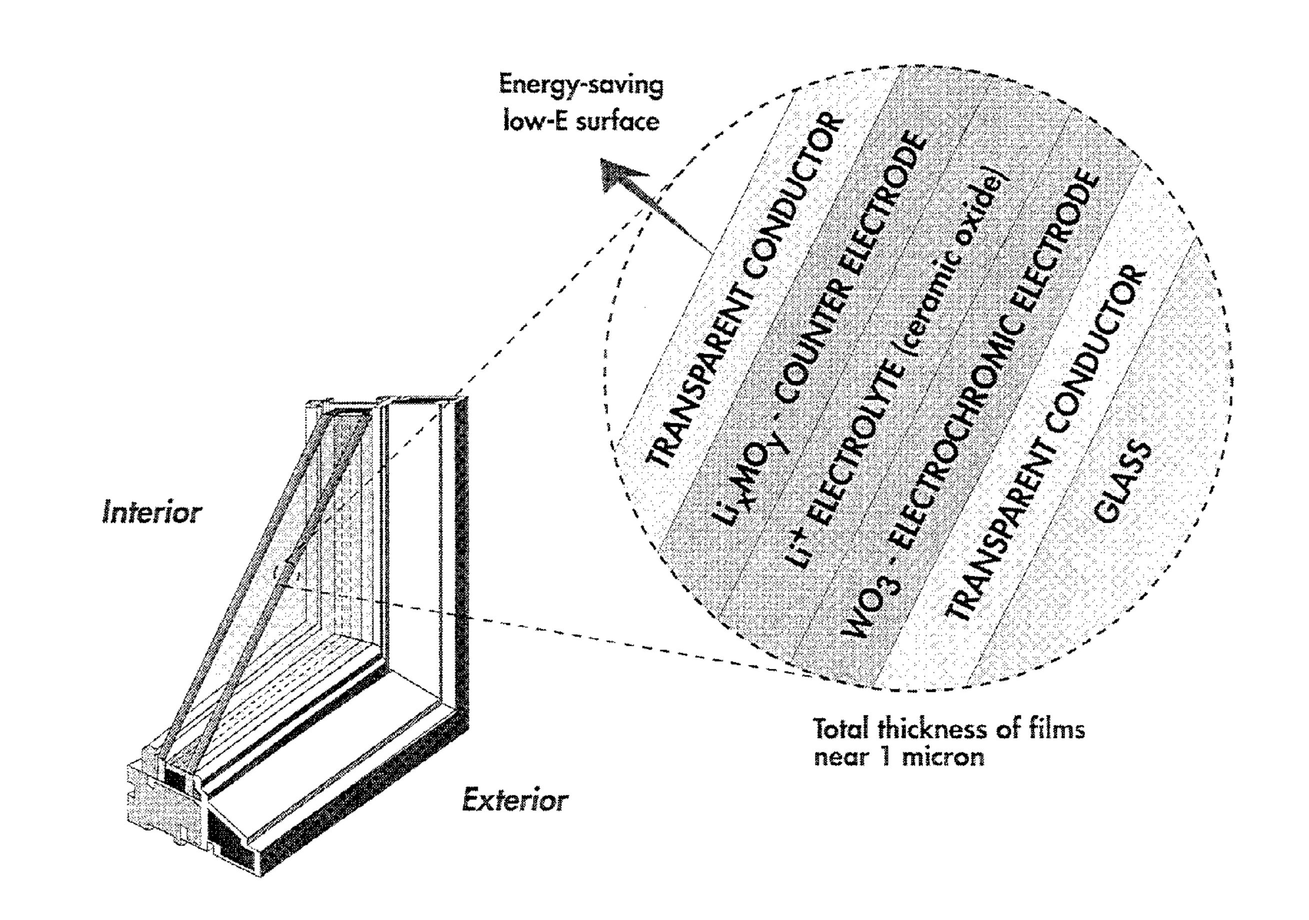
Outline

- EC Device Structure
- EC Performance
- Application with PV
- Durability Testing Results

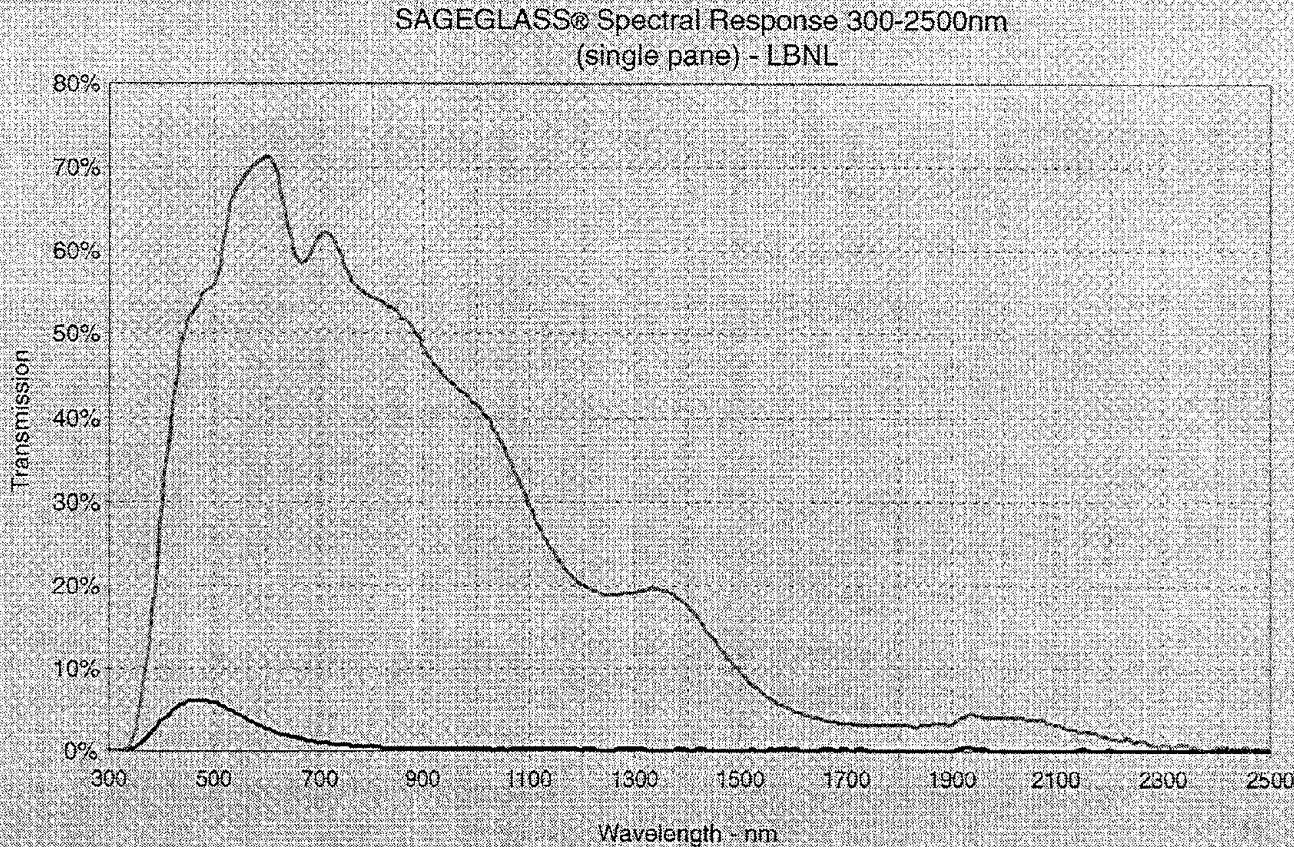
EC Device Characteristics

- All ceramic multilayer thin-film structure
- EC device incorporated into double pane IGU or laminated
- Can be switched between colored and bleached states or any point in between
- Capability for significant energy savings when used in a window
- Pleasing visual characteristics
- Designed for manufacturability and low cost

SAGE EC IGU in a Window Frame

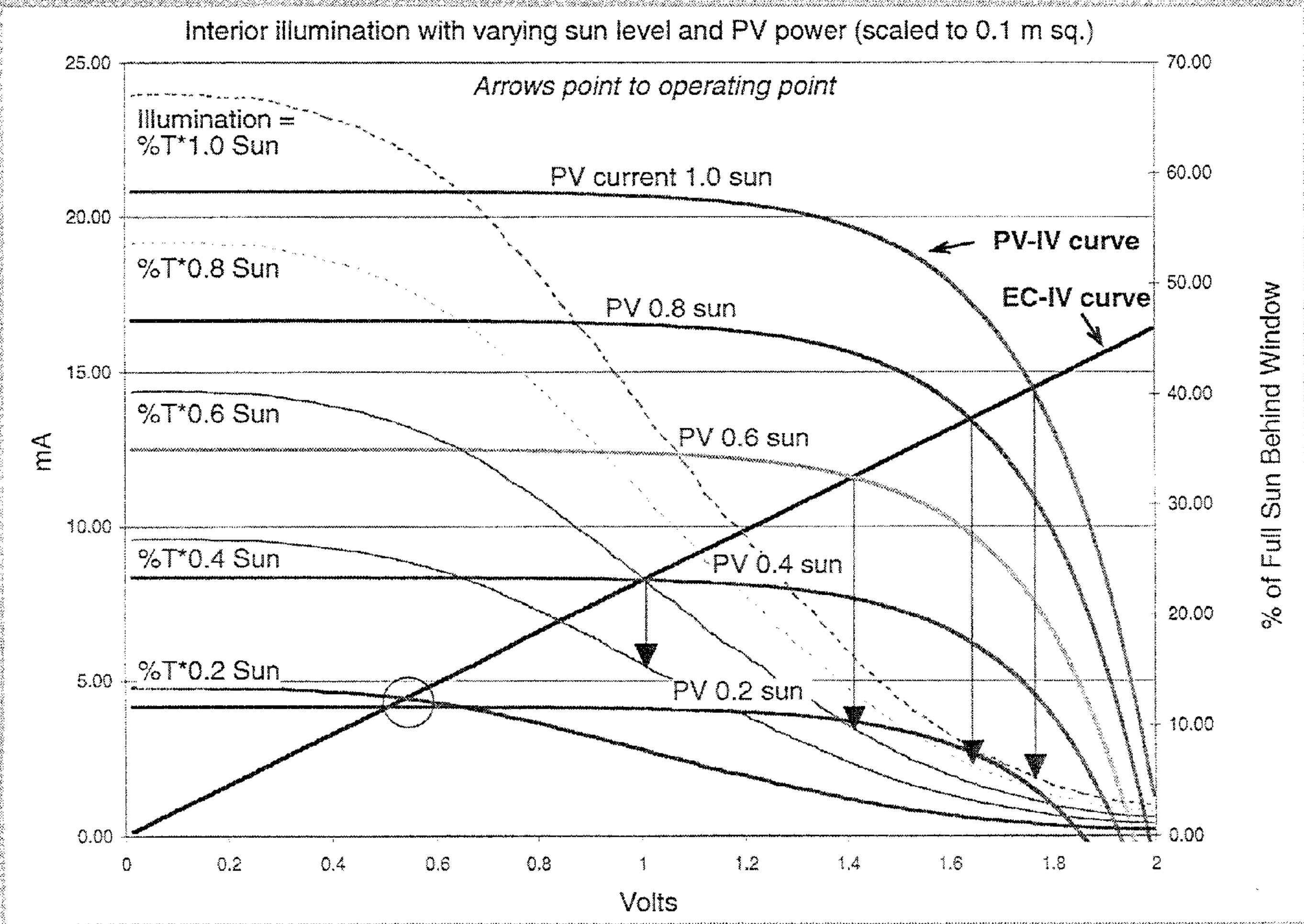


Sageglass® Performance Parameters

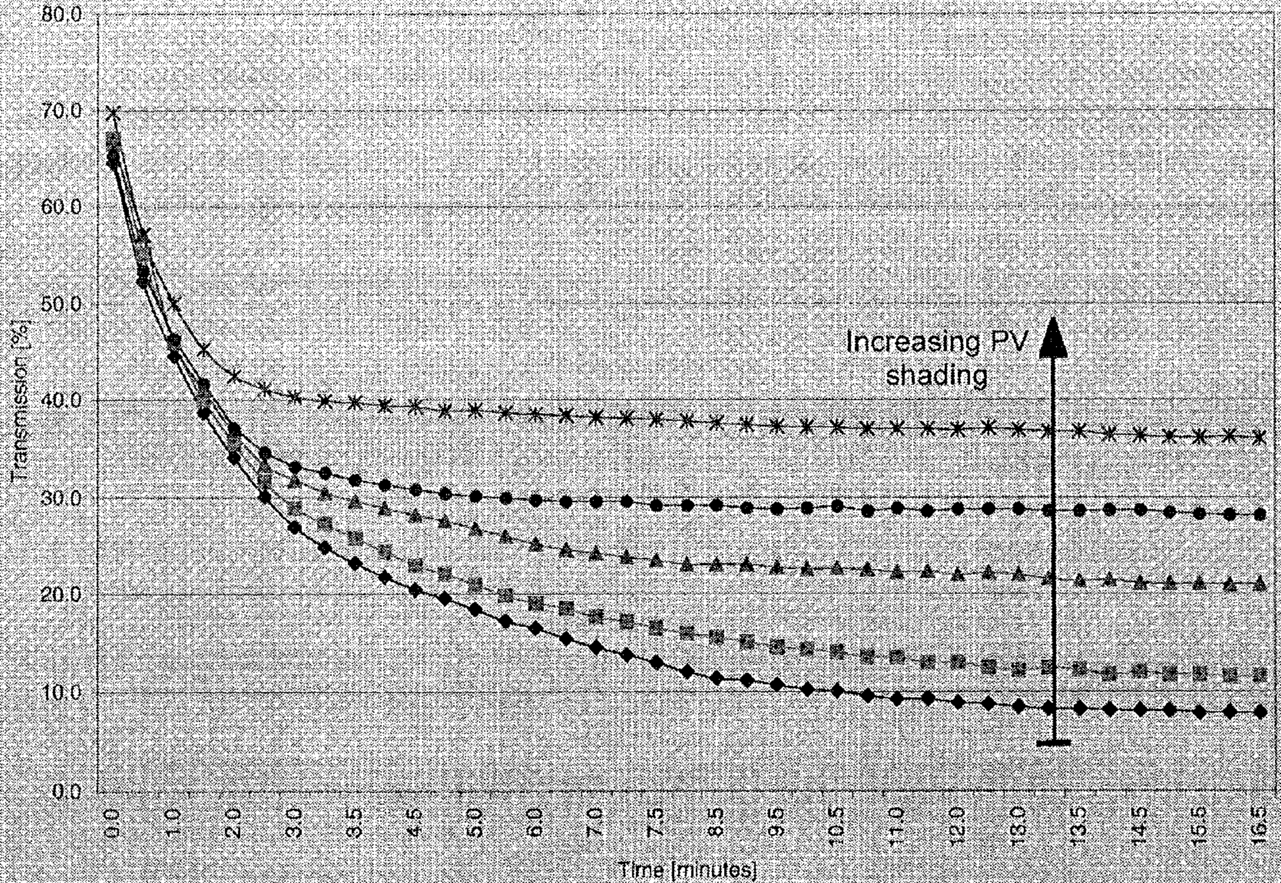


Parameter	Clear State	Darkened State
Visible Transmission	59.1%	3.5%
SHGC	0.43	0.10
U-Value	0.33	0.33
UV Transmission	5%	1%

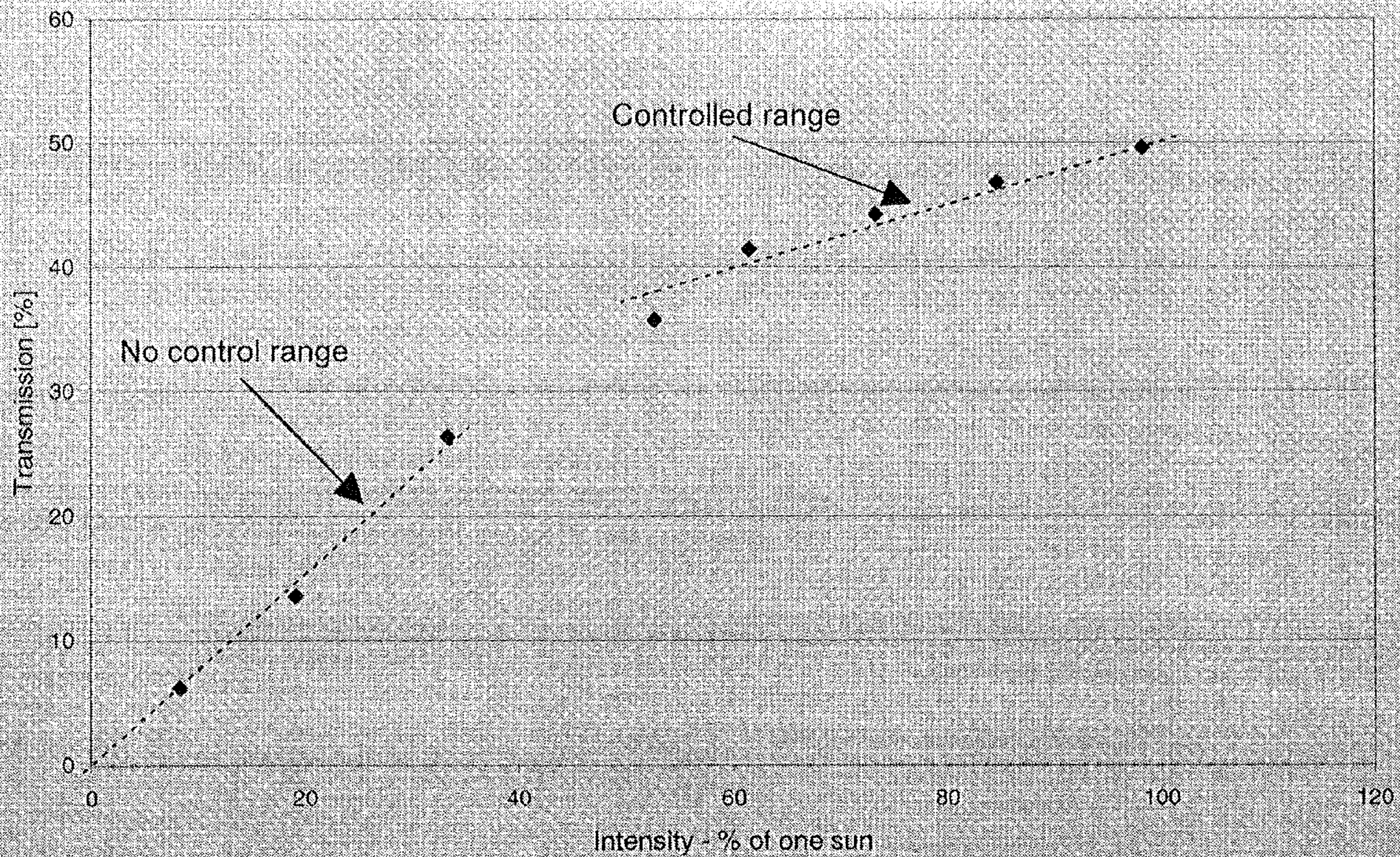
Steady State Interaction of EC and PV



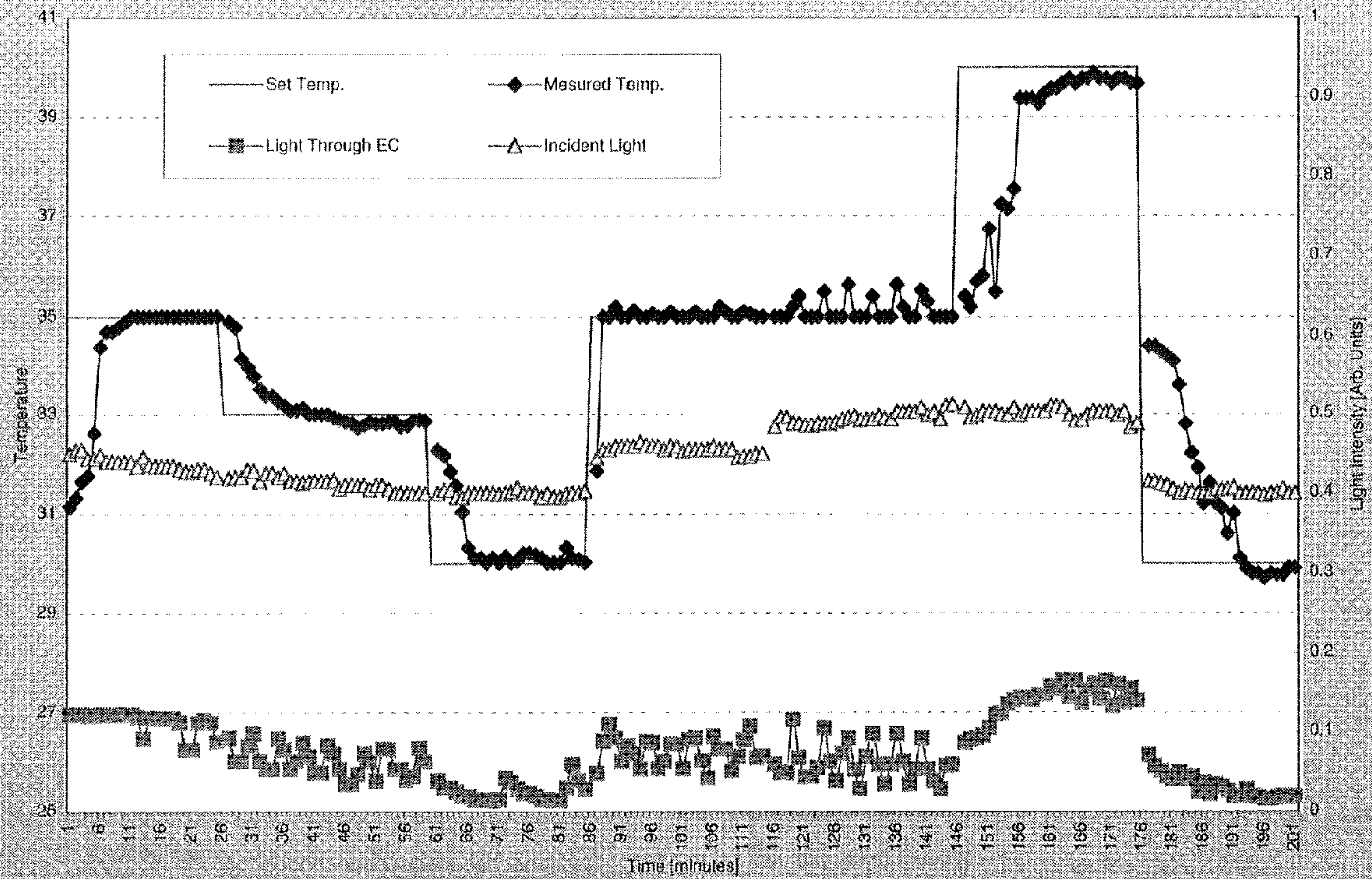
Performance of PV-EC Prototype at 0.75 Sun



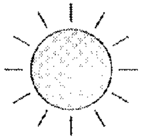
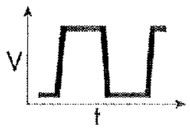
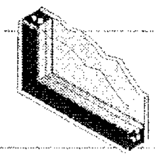
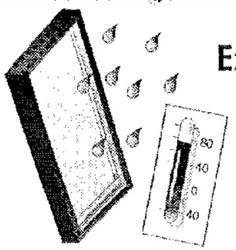
PV-EC Prototype - Response to Changing Light Conditions



Temperature Regulation Using Integrated PV-EC System with Remote Control



Electrochromic IGU Stresses

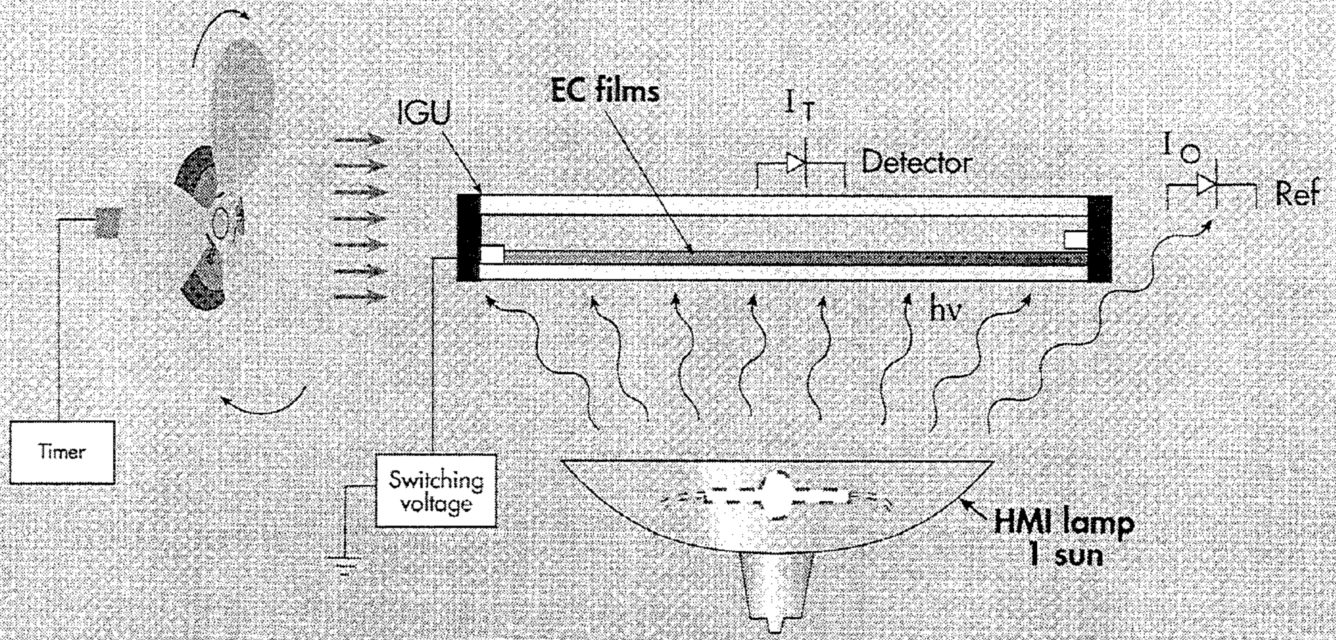
	Origin	Energy	Application Mode	Stress Type
	**Solar radiation**	UV/Vis	Intensity, spectrum	Photochemical
		Thermal	Temperature	Chemical reaction
			Gradients	Mechanical
	**EC control system**	Electrochemical	Voltage level Voltage waveform Repeated cycling	Electrochemical reaction Microstructural/structural volume changes
	**Internal IGU environment**	Chemical	H_2O Air - O_2, CO_2	Chemical reaction
	**External IGU environment**	Physical - force	Intensity Gradients	Mechanical
		Thermal	Ambient temperature	Chemical reaction
			Gradients	Mechanical

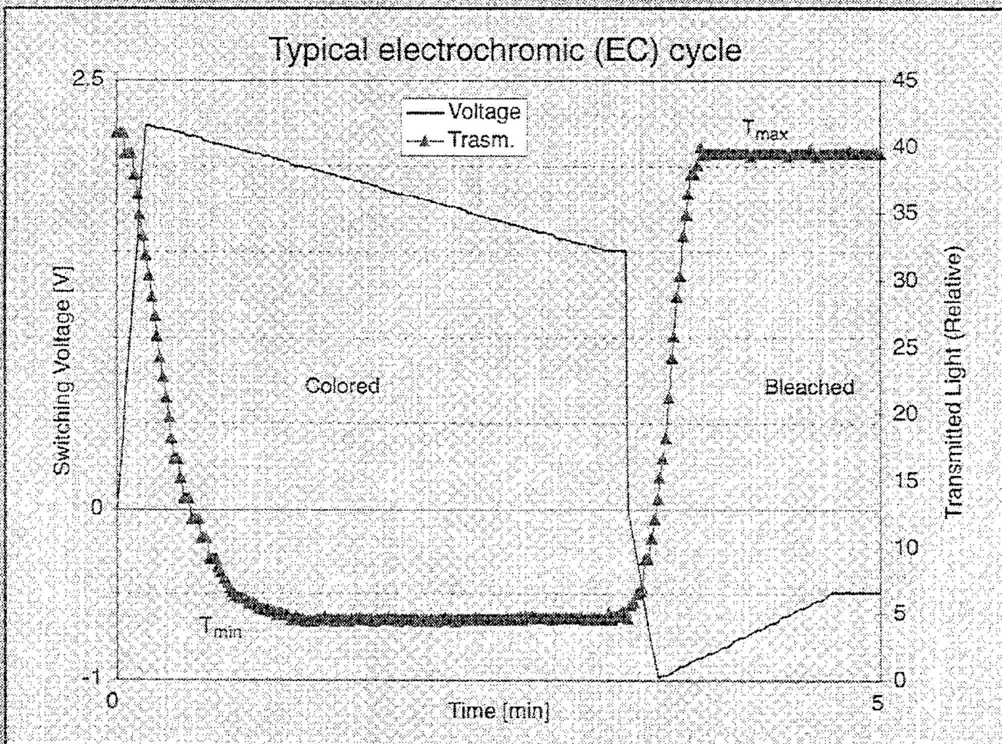
HMI Irradiation - with Temperature Cycling

Long-Term Test to Accelerate Solar Energy Exposure and Day/Night Temperature Fluctuations

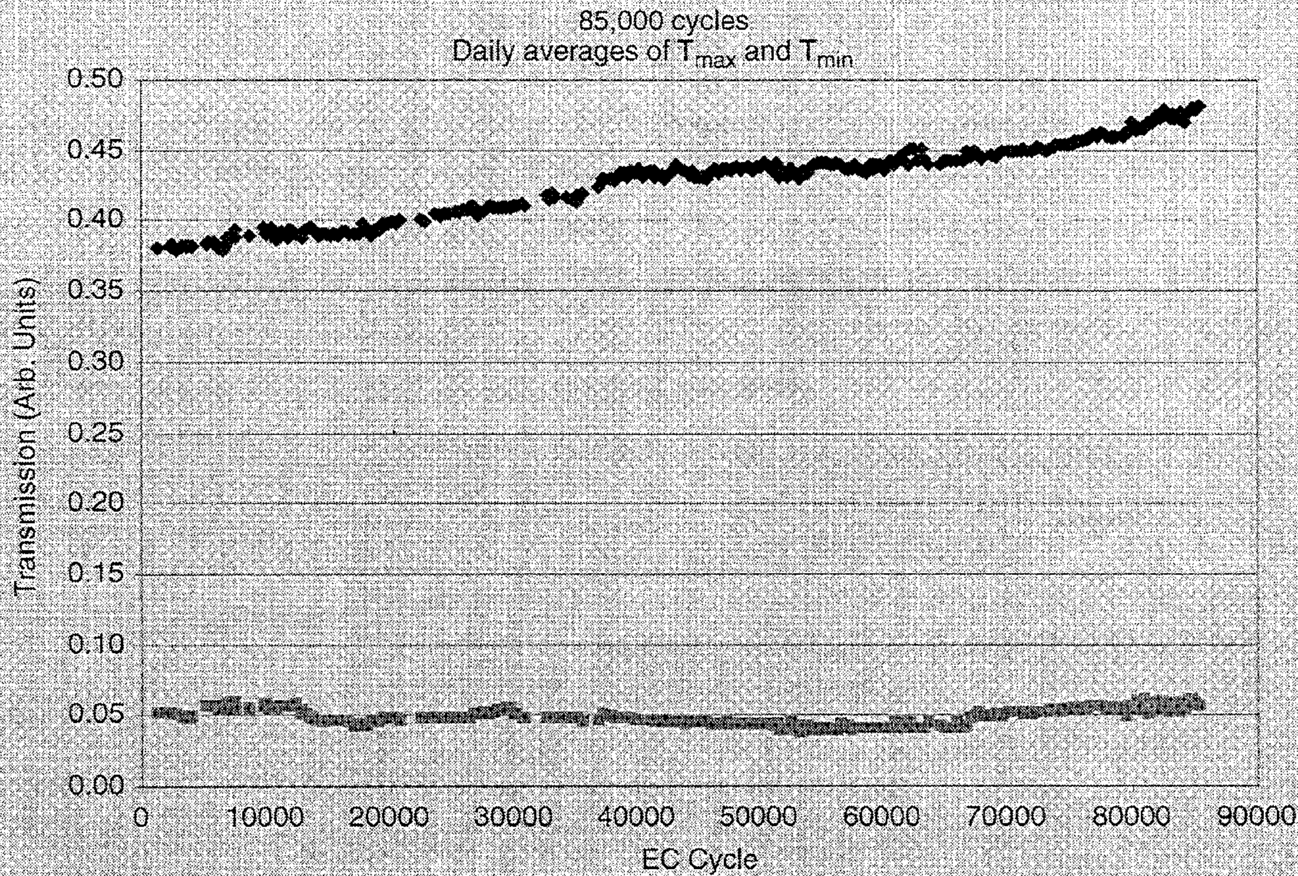
- Continuous 1-sun irradiation - HMI lamp
- Switching voltage
  - 5 minute EC duty cycle - 288 cycles/day
- Simultaneous temperature cycling
  - 40°C to 90°C
  - 4-hour duty cycle - 6 temperature cycles/day

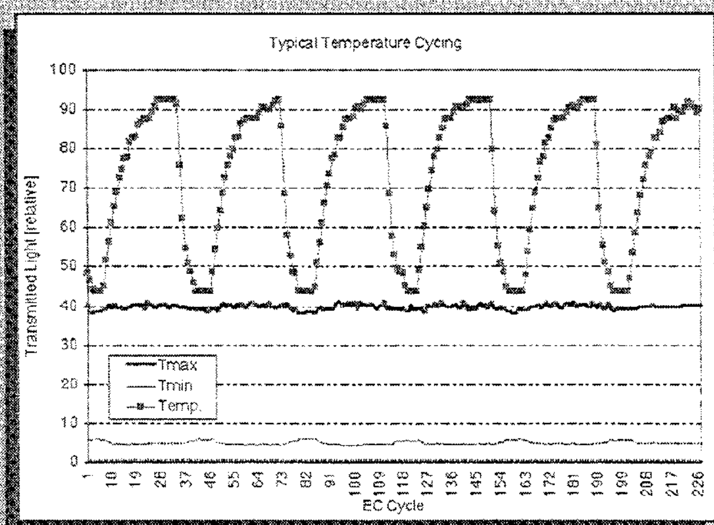
HMI - Irradiation





EC Cycles


85,000 cycles
Daily averages of T_{max} and T_{min}
Transmission (Arb. Units)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
EC Cycle


Typical Temperature Cycing
Transmitted Light [relative]
Tmax
Tmin
Temp.
EC Cycle

Results

No Significant Optical Contrast Degradation

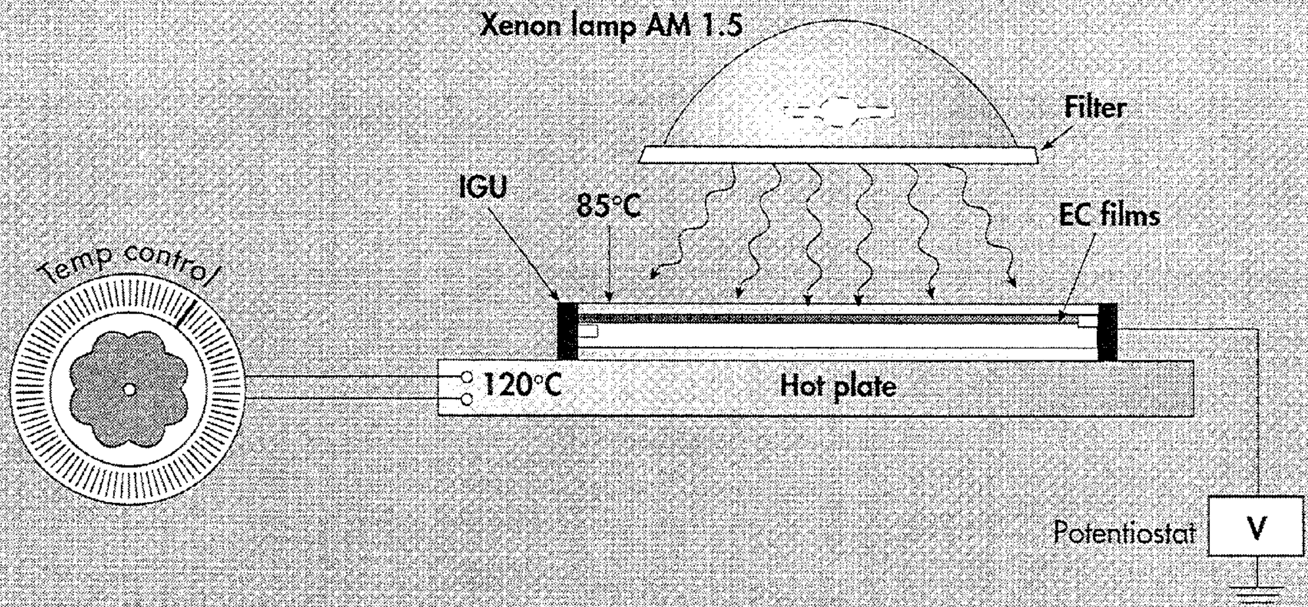
- 85,000 EC cycles - over 300 days
  - EC switching equivalent to 20 years @ 10 cycles/day
  - Day/night temperature cycling accelerated 6X
  - 1-sun intensity - 24 hours/day

Solar Simulator - High Temp

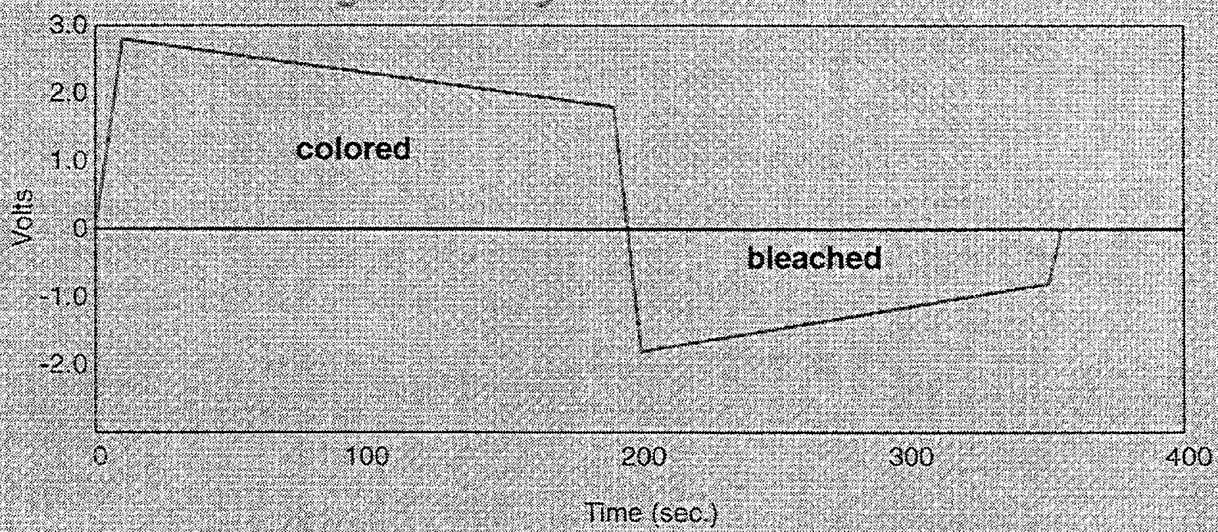
Samples were exposed to simulated solar irradiation while rapidly cycled between colored and bleached states

- Atlas XR260 Solar Simulator
  - Tests carried out by National Renewable Energy Lab
  - Filtered Xenon lamps; continuous AM 1.5 irradiance
- Device temperatures as high as 111°C
  - Hot plate temperatures 120°-189°C
- EC switching cycles
  - 6" device: 626 cycles per day
  - 12" device: 248 cycles per day
- Periodic transmission measurements at 22°C
  - 550 nm

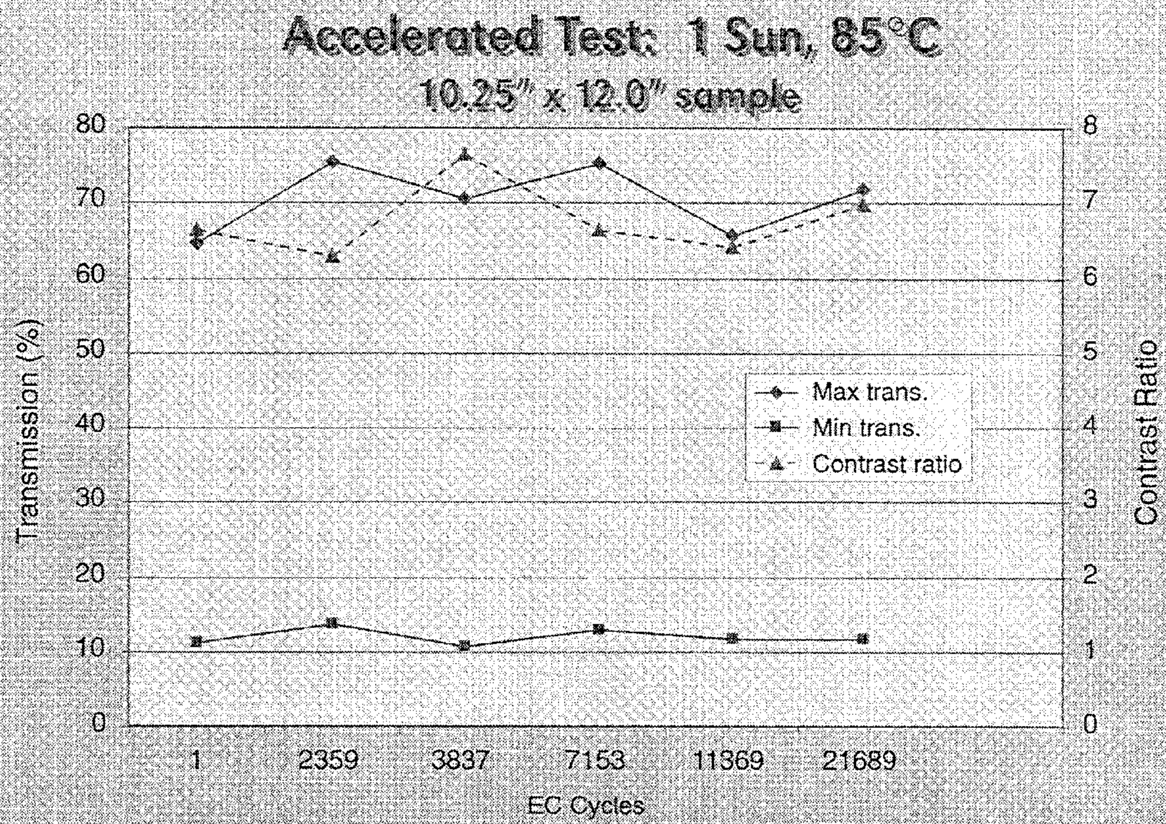
Solar Simulator - High Temp

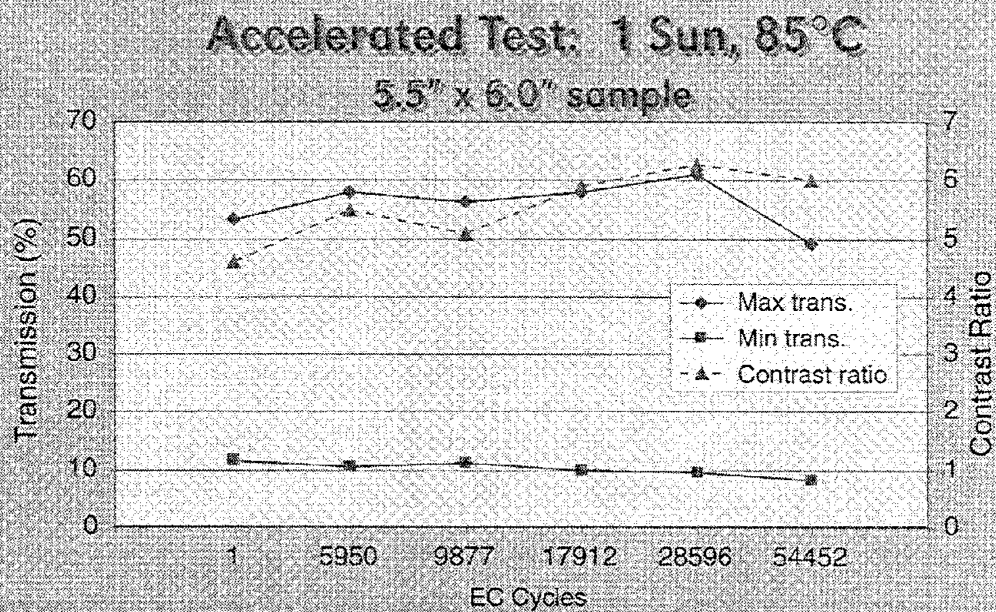


Single EC cycle - 12" device



Solar Simulator Test Data





Solar Simulator - Results

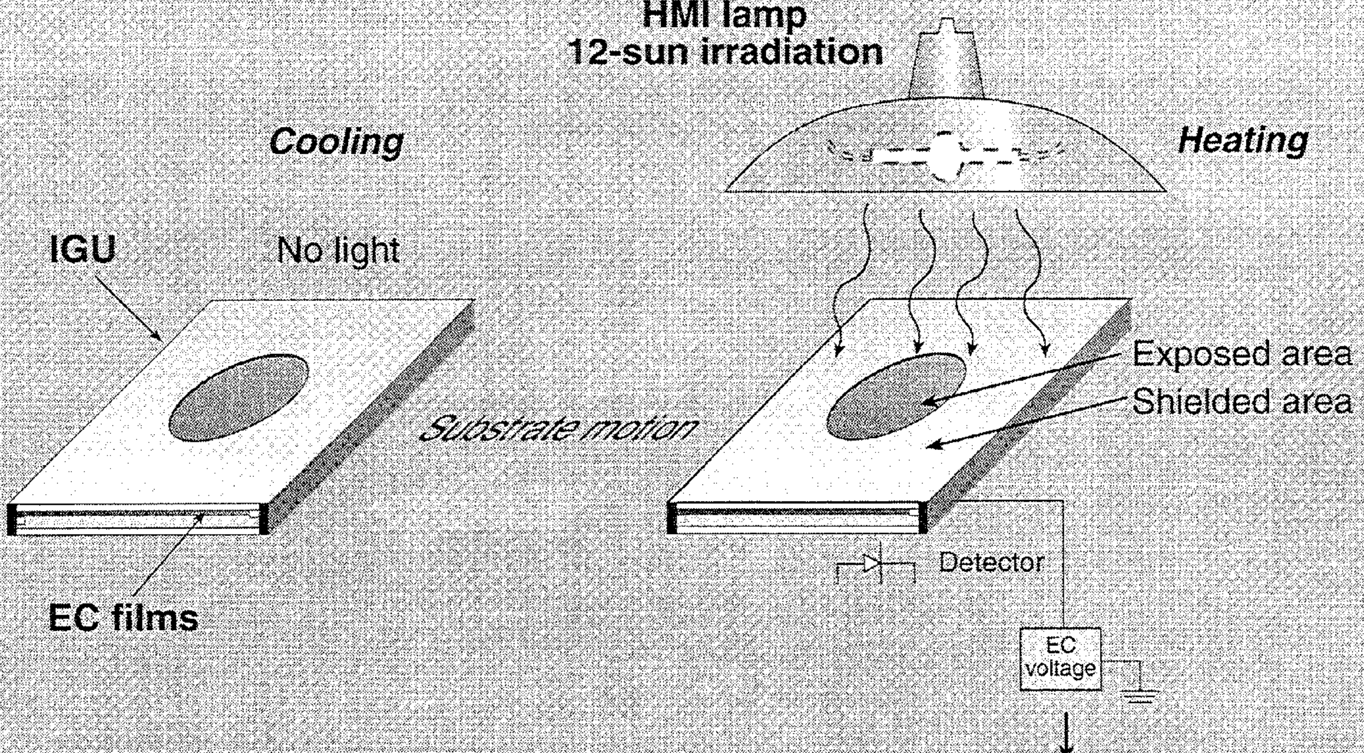
No Significant Degradation Observed

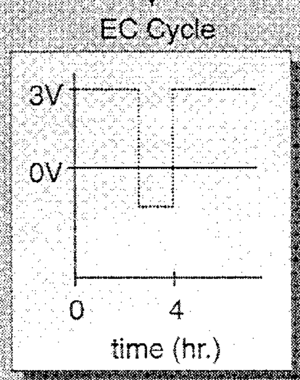
- Rapidly switching devices achieved over 54,000 EC cycles
  - Contrast ratios relatively unchanged over 4-month test
- All-ceramic lithium EC devices extremely durable at elevated temperatures
  - 85°C device, 120°C hot plate
  - When hot plate reached **189°C**, polymer seals degraded and residues contaminated device surfaces

High Intensity Light Exposure

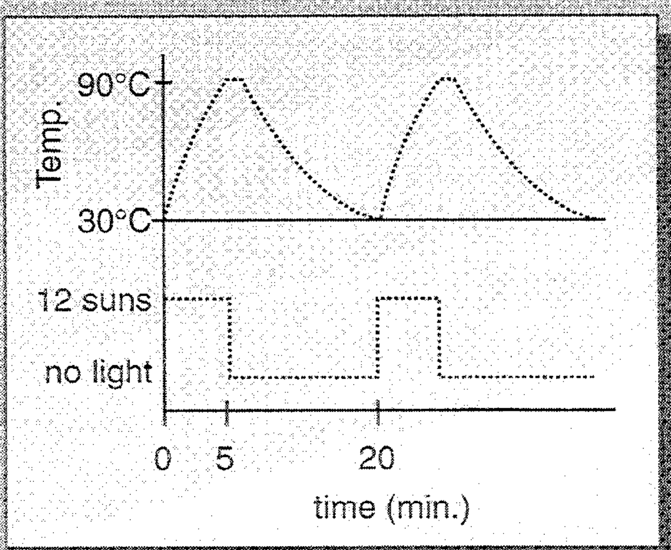
- Extremely accelerated test to evaluate photoelectrochemical durability
- All-ceramic lithium device in IGU is exposed to cycled 6-sun and 12-sun irradiation while being slowly colored and bleached
  - 12 light exposure (and temperature) cycles per EC cycle
- High intensity cycling continued after EC device exposed to humid ambient conditions
  - Light transmission compared for shielded and exposed areas

High Intensity Light Exposure

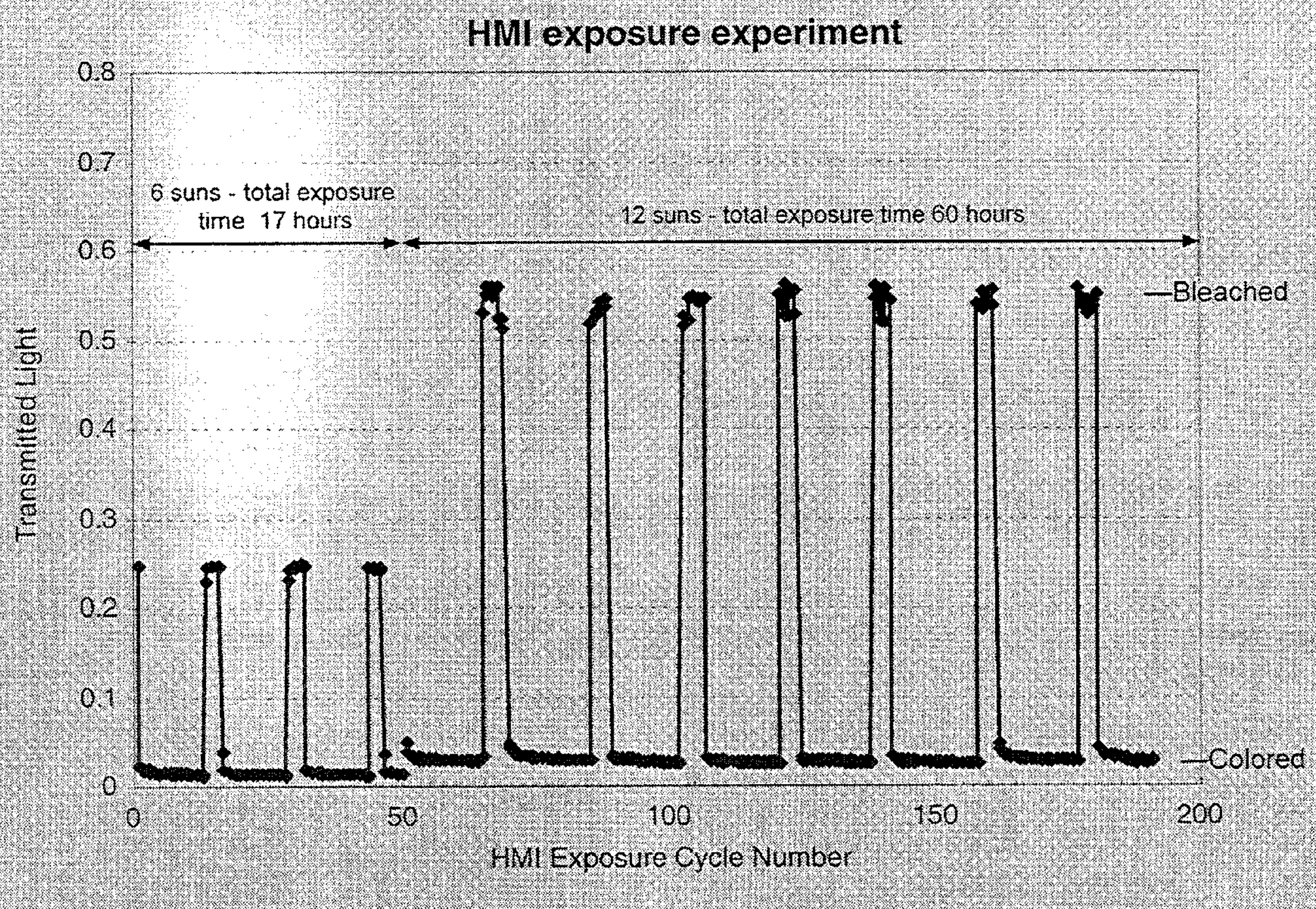




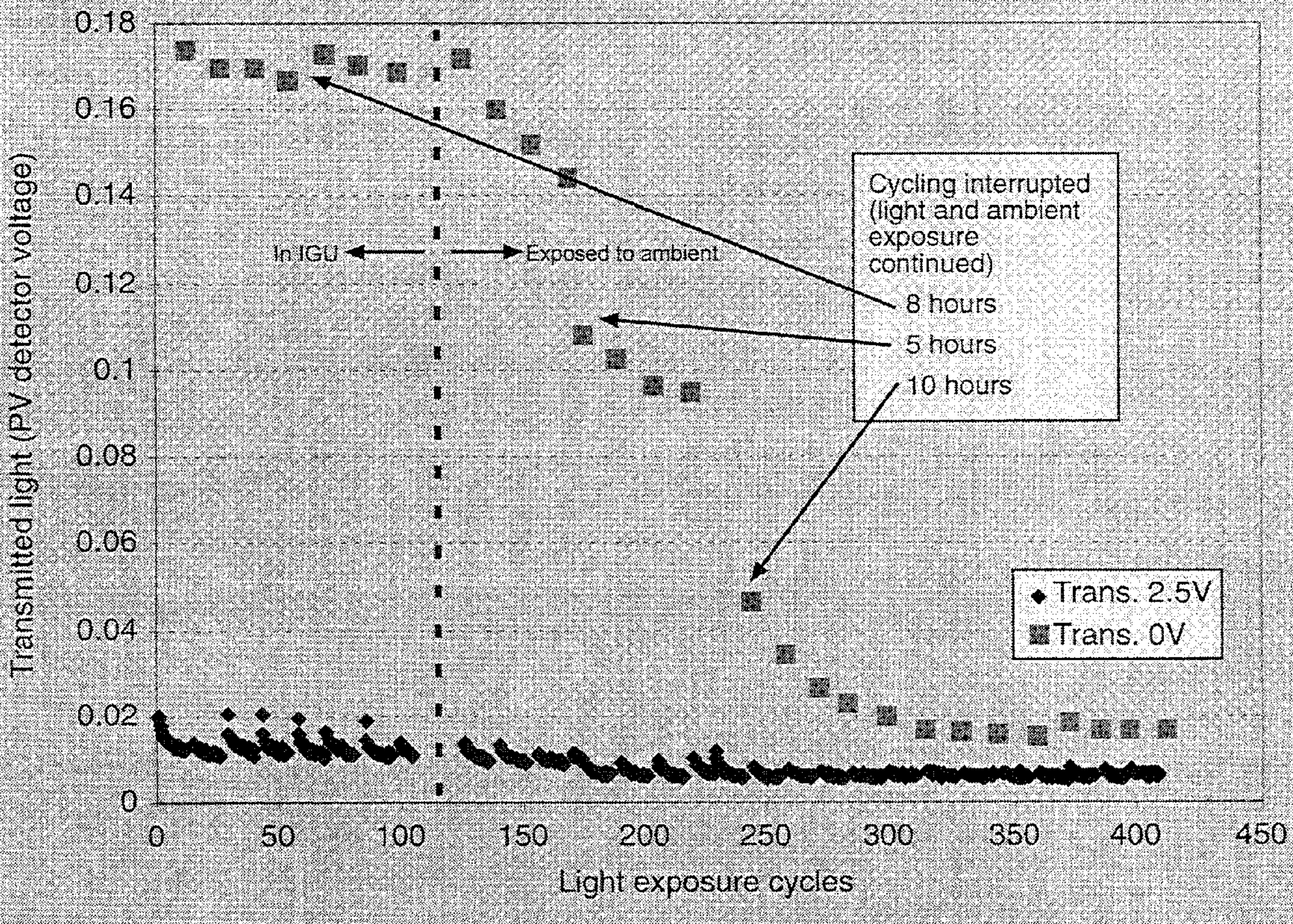
Temperature Cycle



Photoelectrochemical Durability of EC System



Effect of Ambient Exposure with 6-sun Cycling - Transmission Response



High Intensity - Results

Extremely Robust Performance During Multiple Sun Exposures

- All-ceramic lithium device in a standard IGU shows no degradation of switching performance after nearly 200 extreme irradiation/temperature cycles
- In humid ambient, the exposed area of the device slowly loses transmittance in the bleached state
  - This photoelectrochemical reaction is not observed in shielded areas

Direct Solar Exposure - Arizona Desert

12" EC Devices Powered by PV Arrays Remained Colored Most of the Day

- Devices on solar tracker
  - Maximum exposure to natural solar load
- Samples started in 1996 have been operating in the desert for two years

Arizona Desert - Results

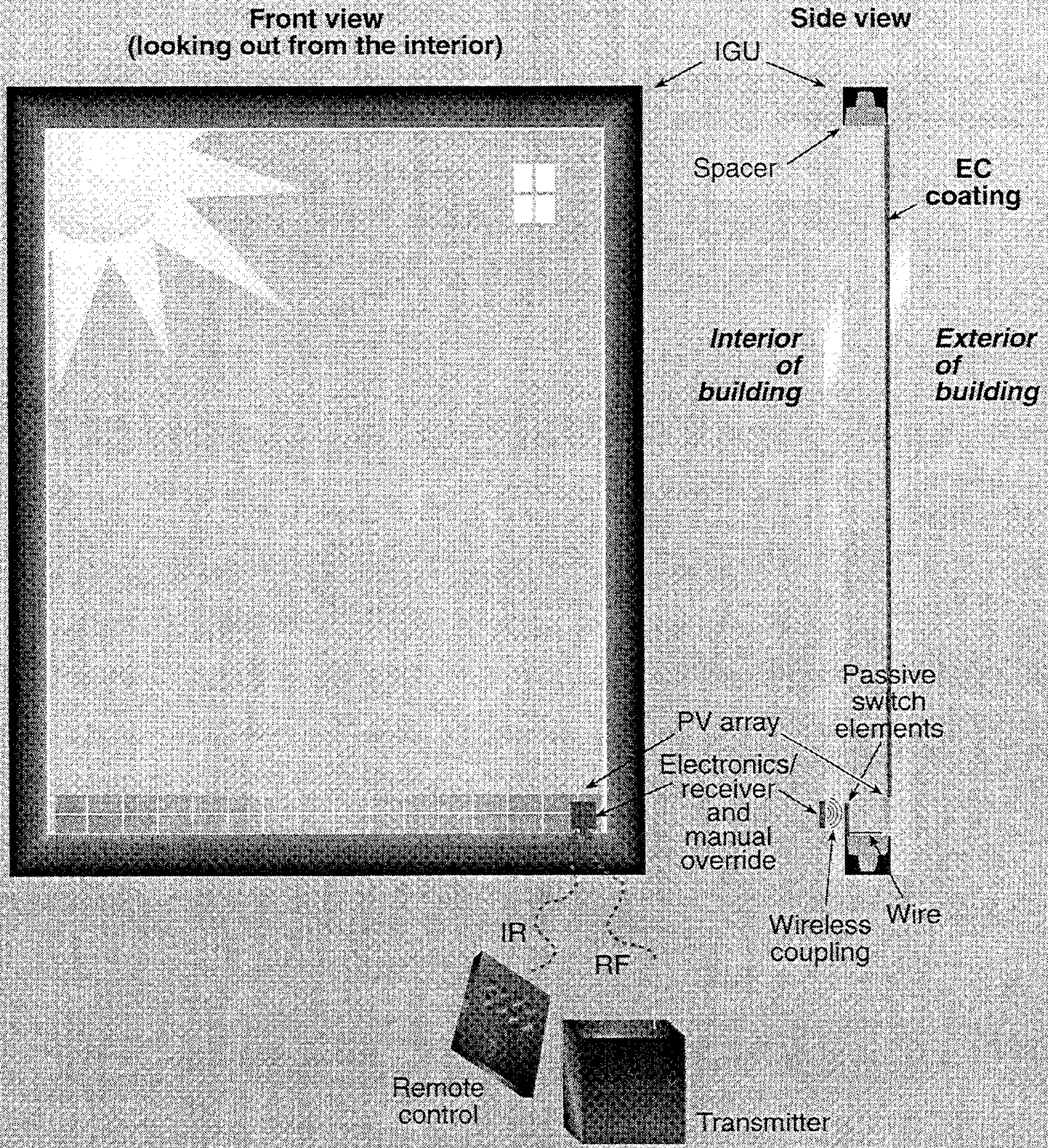
All-Ceramic EC Device Continues to Switch and Meet Performance Requirements After Two Years Desert Exposure

- EC device switches once a day; transmission in colored state remained fairly constant for duration of test
- Colored EC device reached temperatures up to 25°C higher than ambient

Summary
SAGE EC Device

- Structure compatible with low-cost thin-film manufacturing
- Wide coloring range and energy saving capability
- Can be mated with PV for stand-alone application to:
  - Control light
  - Control heat
- Extremely durable - can withstand
  - High temperature
  - High light intensity
  - Rapid cycling
  - Significant overpotential

PV-EC Window Concept



Gone with the Wind?

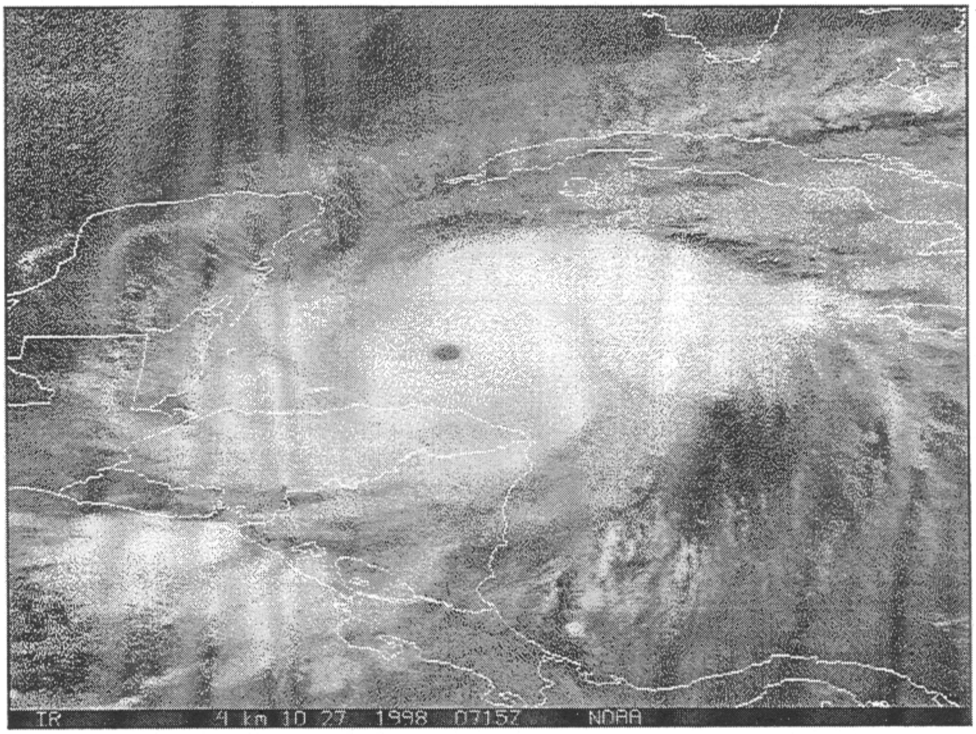
Approaches to Wind Stability for Ballasted Flat Roof PV Systems

Edward C. Kern, Jr.

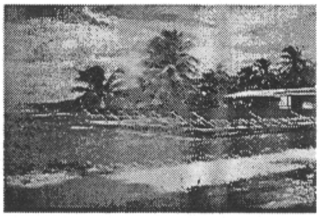
Ascension Technology, Inc.

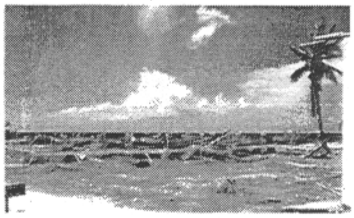
1998 PV Performance and Reliability Workshop

November 3-5 Cocoa Beach, Florida



Hurricane Georges





- Isla Mona was directly hit by Hurricane Georges with average wind speed exceeding 120 mph
- Three second gusts in hurricanes are statistically 162% of average wind speed (about 195 mph)

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PV Benefits on Flat Rooftops

- Huge areas available at no cost
- Secure without fences
- Unshaded as trees already cut
- Cost savings from substitution of roofing materials
- Proximity to day time peak electric demand

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PV Liabilities on Flat Rooftops

- Penetrations of watertight membranes
  - Expensive and can lead to leaks
- Weight of PV panels
  - New construction has little load carrying capacity beyond snow loading

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Other Considerations

- Benefits
  - Tenant gets near term marketing opportunities
- Liabilities
  - Operator assumes long term unknown risks

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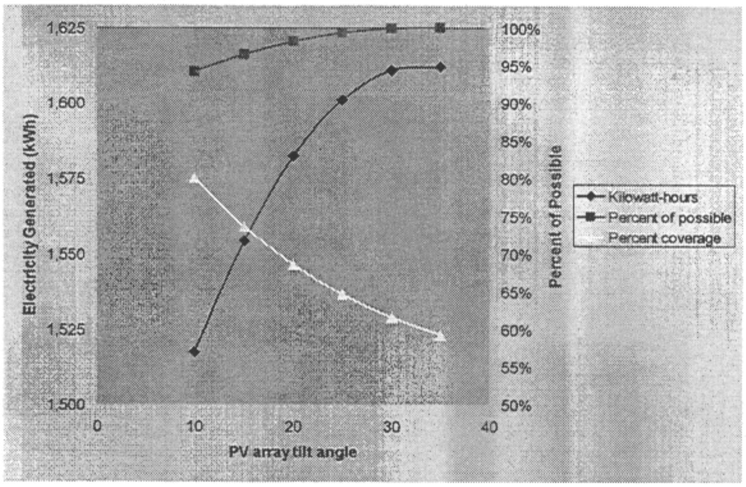
Array Tilt Angle: Boston



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Ascension's Flat Rooftop System

- Challenge: PV systems for the first EPA PV DSM on Buildings projects in 1992
- Response: Evolve from successful pitched roof design used since 1984
- Implementation: NEES (Newburyport, MA) 11/92, Bradlees (Medford, MA) 12/92, NYSEG (Plattsburg, NY) 4/93, Northeast Utilities (Hartford, CT) 4/93

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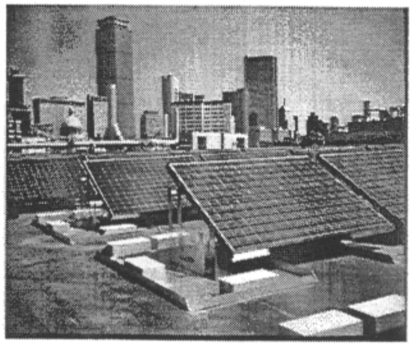
Basic Ballast Mounting Concept

- Galvanized steel tray filled with rock or tile
- Risers support PV modules
- Modules attach with pin assembly design
- Wiring harness and junction box attach to RoofJack™



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Field Experience

- EPA Round #1, #2, #3 Projects
- Adapted for ground mounting in Nevada and India
- UPVG Round #1, #2 TEAM-UP Round #1, #2 projects

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First Wind Problems

- Providence, RI in March storm 1997
- Wilmington, DE in February storm 1998
- Trays moved during peak wind gusts
  - wind speeds not recorded
  - no one hurt, no panels broken
- Led to a PV:BONUS2 project to study and improve design to withstand high winds

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PV:BONUS2 Project

- Phase 1: Study, Planning and Controlled Testing
- Phase 2: Development and System Field Testing
- Phase 3: Deployment and Market Testing

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Phase 1 Activities

- Literature search and review (Professor Robert Akins)
- Code requirements (Jeff Shingleton, P.E.)
- Full scale field measurements (Joseph Bernier)

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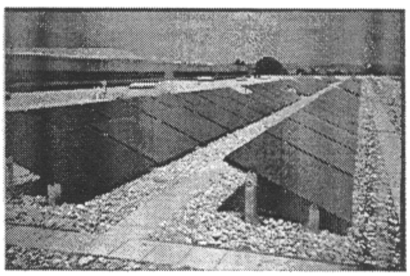
Array Wind Exposure

- A typical installation with northern and end of row panels having the greatest exposure to lifting forces
- Inside panels are shielded from north
- Southern row held down by south wind



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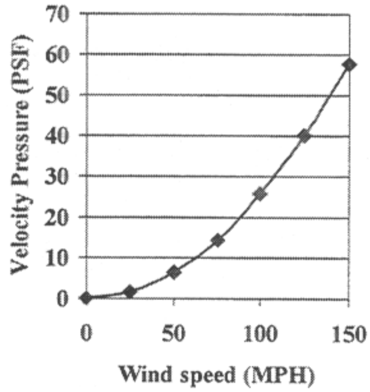
Wind Force Basics

- $F = 1/2\ \rho\ V^2\ A\ C_f$
- Velocity pressure is $1/2\ \rho\ V^2$
- Force coefficients C_f typically near unity
- Slotted wing sections can reach $C_f = 4$
- Worst PV case is $C_f = 2.3$ at corners



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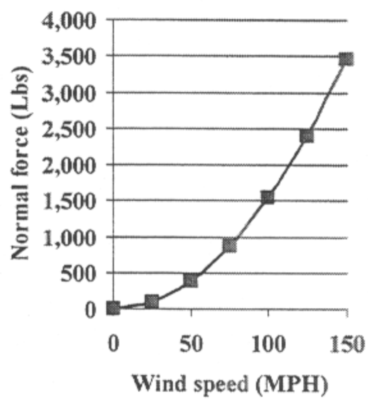
Force on a single module

- $F = 1/2\ \rho\ V^2\ A\ C_f$
- For a large module (ASE) $A = 26.13\ ft^2$
- For an array northern corner position $C_f = 2.3$
- Panels are rated at 50 PSF, about 1,300 lbs., and tested to 75 PSF, about 2,000 lbs.



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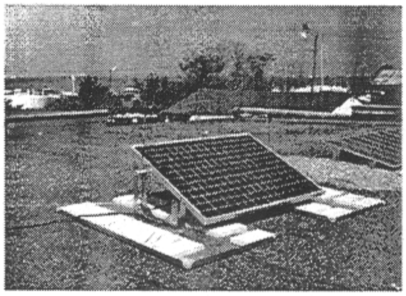
Newburyport Measurements

- Site has open, over water exposure from the north
- Original ballast tray test site (Siemens)
- Confirming data from literature review
- Measurement strategy, sample if V > 20 mph



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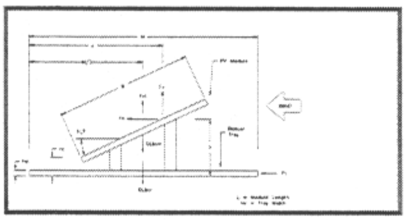
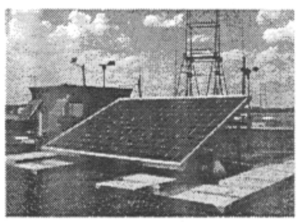
Resolving Wind Wind Forces

- Lifting forces resisted by gravity and adjacent panels
- Sliding forces resisted by shear stresses in panel/roof interface
- Overturning moments resisted by gravity





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Building Codes

- U.S. moving to the International Building Code (IBC) in year 2000
- ANSI/ASCE Standard 7-95 "Minimum design Loads for Buildings and Other Structures" now widely accepted and will be incorporated in to IBC

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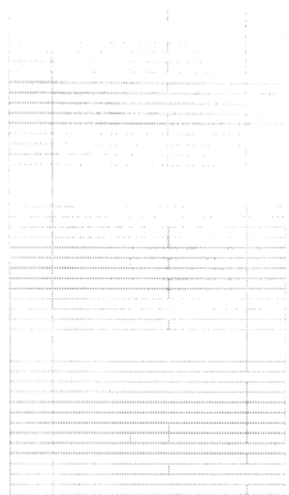
Single Panel Model

- Developed by Jeff Shingleton, P.E.
- Uses ASCE 7-95
- Lifting, sliding and overturning
- There is no proper C_f in ASCE 7-95, need better sources



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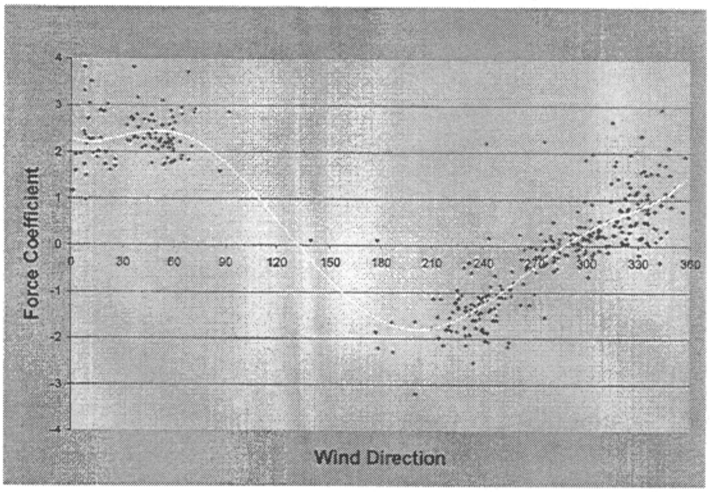
Newburyport Data: Single Panel



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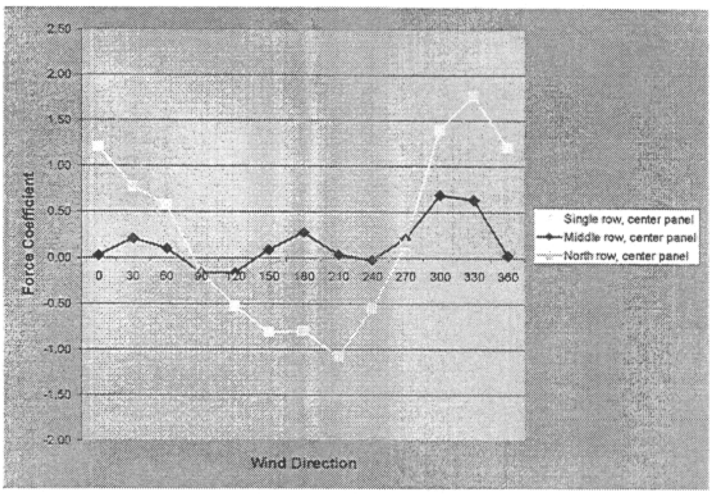
Partially shielded center panels



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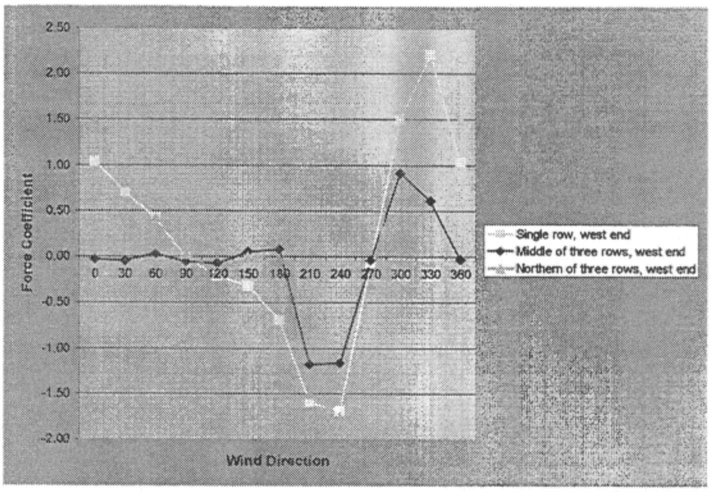
Exposed row end panels



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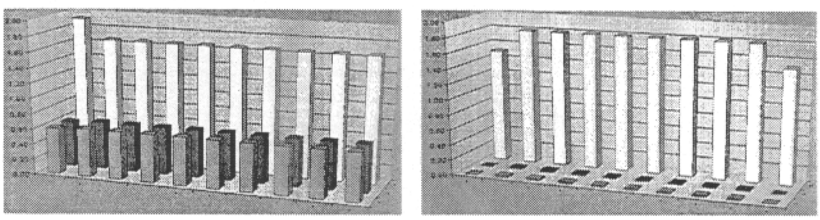
Wind Forces on 3-Row Array



- Left graph: northwest wind, maximum wind forces occur at the array corners with winds from the northwest or northeast
- Right graph: north wind forces on internal panels for north winds are minimal

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Design Developments Options

- Greater ballast in each tray
- Enhance sliding friction coefficients
- More row-to-row and panel-to-panel structure, especially in northern corners
- Wind deflection shields along east, north and west sides or the northern corners
- Wire tethers to the northwest and northeast

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PV:BONUS2 Phase 1

- Reporting on wind forces and design requirements

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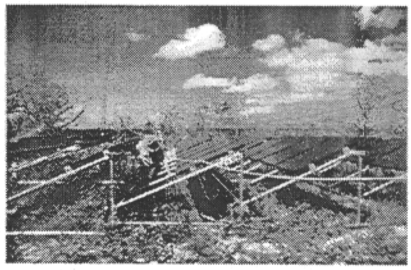
PV:BONUS Phase 2

- Single panel testing at NWTC at Rocky Flats, CO
- Design development and testing
- Array testing
- Alliance building with roofing manufacturers



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PV BONUS Phase 3

- Product manufacturing and market testing

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How we Designed Reliability into the GC-1000 Inverter System

- Dr. Robert Wills
- Advanced Energy Systems
- Wilton, NH
- (603) 654-9322
- www.advancedenergy.com

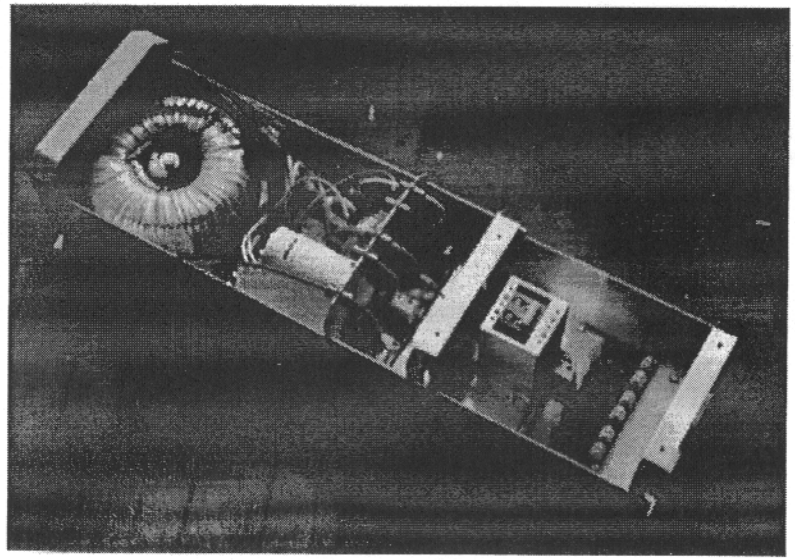
About the GC-1000

- 1000 W AC Output
- Grid Interactive
- UL Listed/ FCC Certified
- 93% Peak Efficiency
- Standard Outdoor Rating
- Low [44-92] &
- High Voltage Versions [54-120V]
- Matching String Combiner/DC Disconnect
- Integral DC Ground Fault & DC Disconnect
- Optional AC Disconnect
- Optional LCD Monitor
- Five Year Warrantee

Advanced Energy Systems

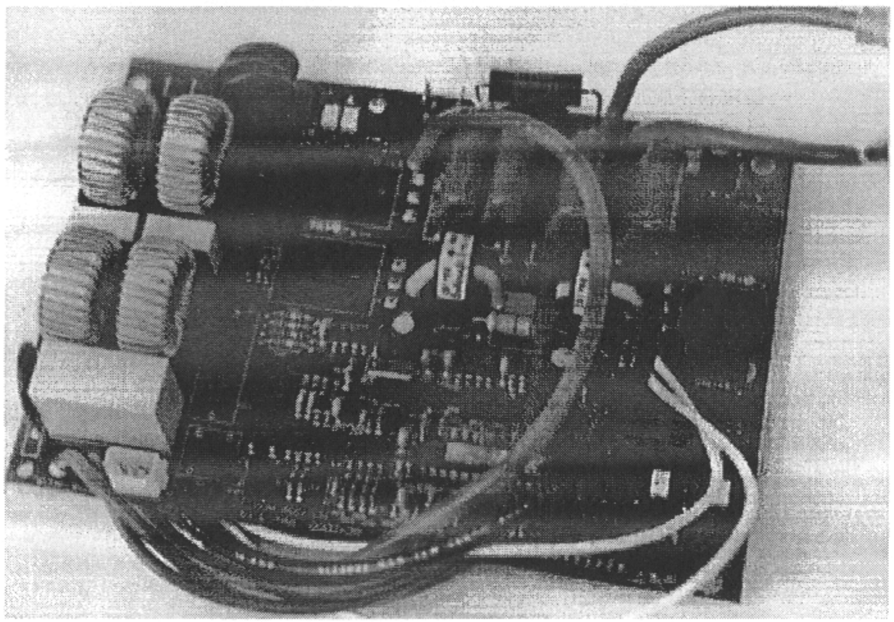
Factors Affecting Reliability

- Parts Count
- Individual Component Reliability
- Component Operating Conditions
- Mechanical Components
- Lightning Protection
- Assembly & Test
- Ease of Installation
- Ease of Service



Parts Count

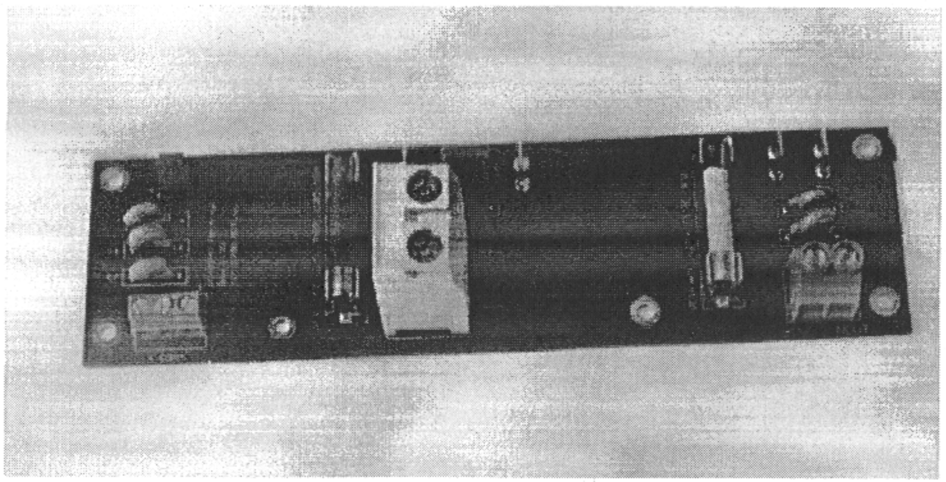
- GC-1000 has fewer parts than any previous inverter
- Fully digitally controlled



Advanced Energy Systems

Individual Component Reliability

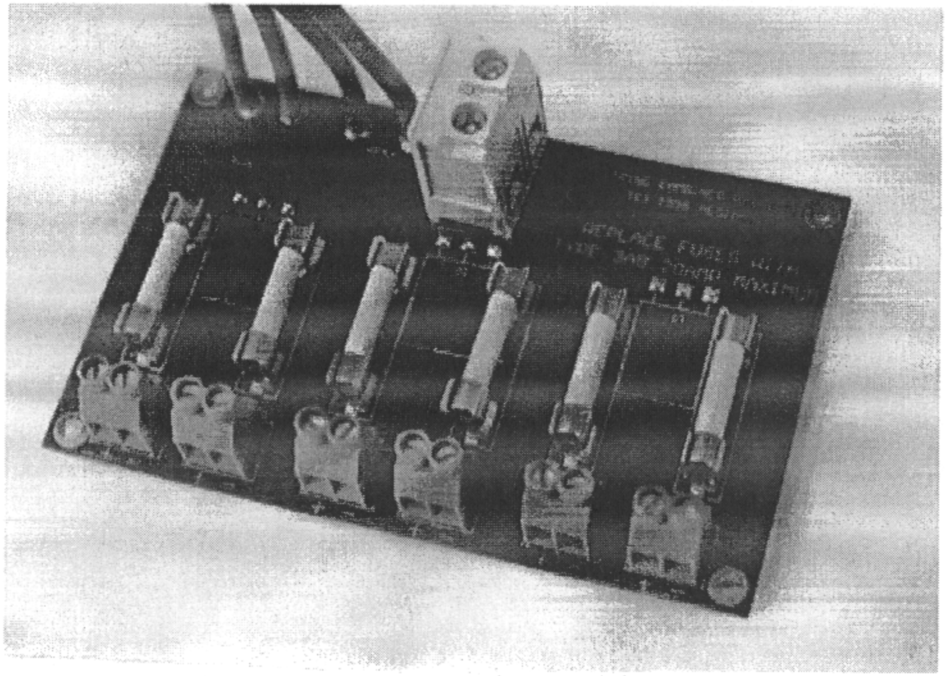
- Long Life Electrolytic Caps
- Relay Operates at Zero Power
- No Fans



Advanced Energy Systems

Component Operating Conditions

- All Components Heavily Derated



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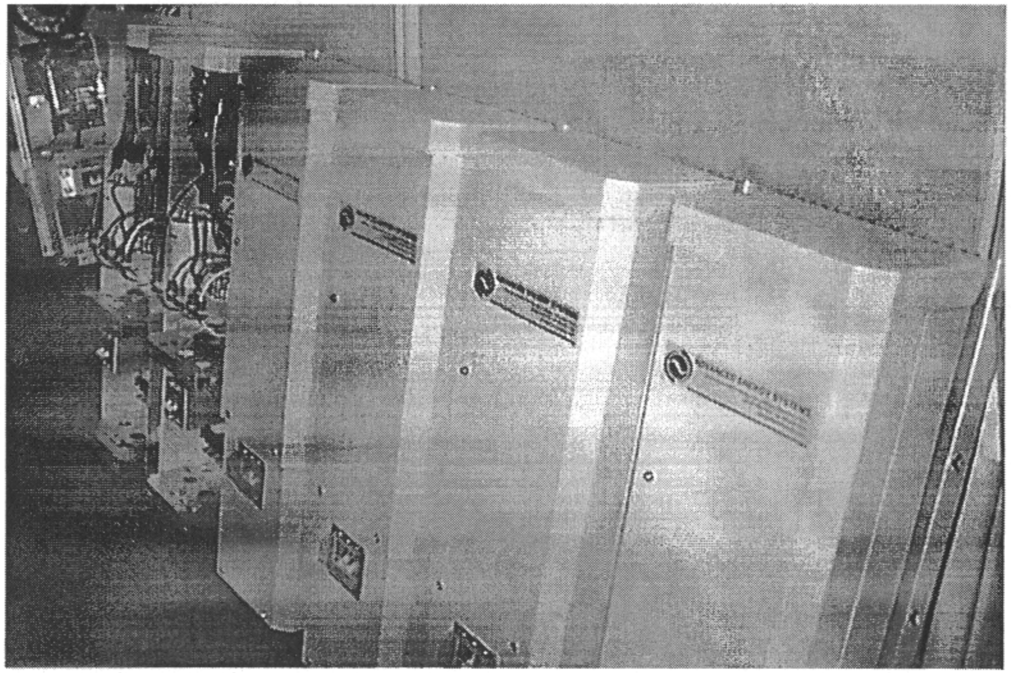
Mechanical Components

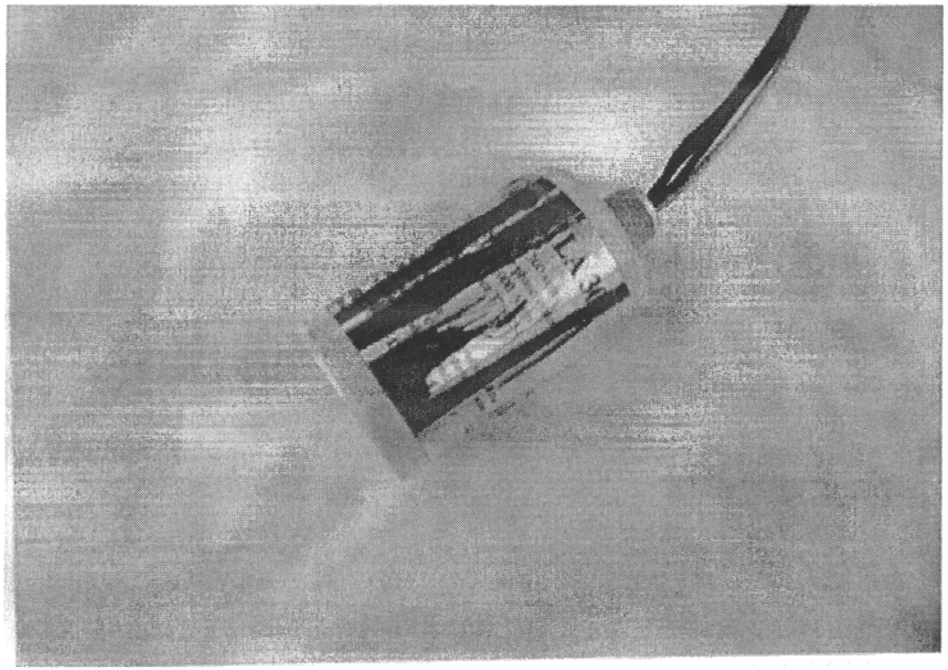
- Outdoor Rated Enclosure
- Passive Cooling
- Automatic Power Backoff on Overtemperature
- Mechanical Overtemp Limit



Advanced Energy Systems

Lightning Protection

- MOVs on Input & Output
- SiOV Protector Mandated for AC Panel
- Transformer Isolated



Assembly & Test

- Qualified Contract Manufacturers
- Automatic Testing
- 24 Hour Burn In
- So Far - Zero Failures in Burn In & The Field

Advanced Energy Systems

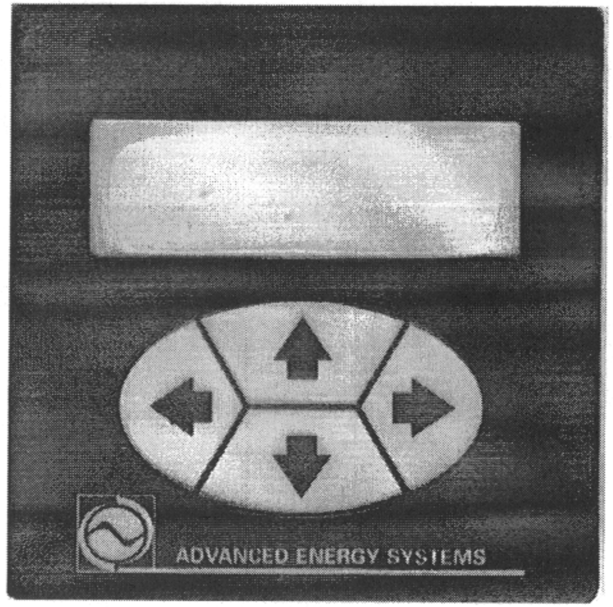
Ease of Installation & Service

- **Installation**
  - Fully Integrated Unit - Just Connect PV & AC
  - Standard Design / Low Margin for Error
  - All NEC Issues Resolved
- **Service**
  - Inverter Section Replaceable
  - Dealer could change a card

Advanced Energy Systems

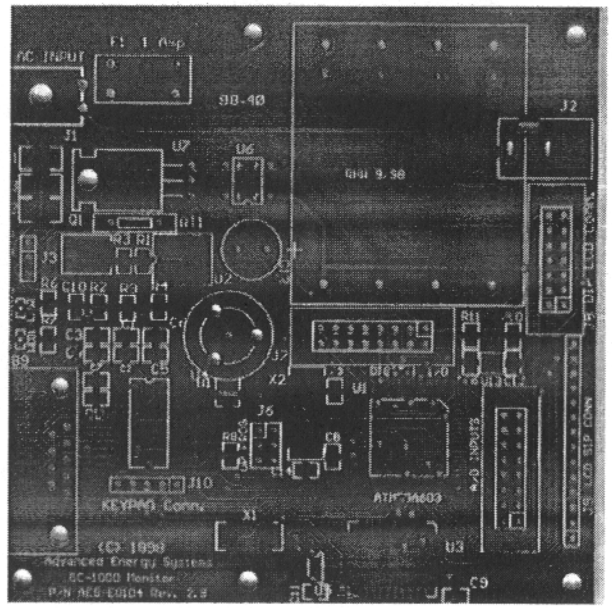
Monitor

- 4 line x 20 LCD
- Atmel Mega 103 Processor
- Electrically Reprogrammable
- 128K program memory
- 1/2 MB Non-volatile (Flash) Data Storage
- Battery Backed RTC
- 3 wire comm scheme
- Modem/PC RS232 Port

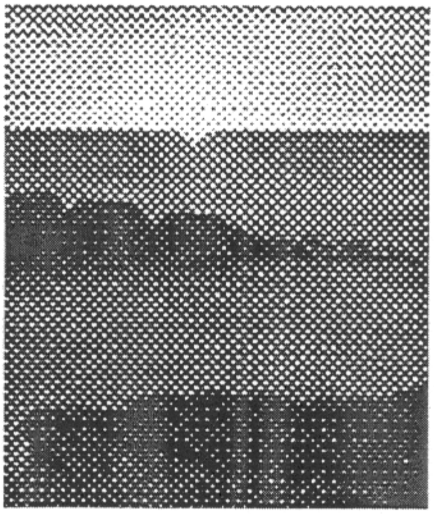


Modular Power Components

- Monitor
- DC-DC Converter (MPPT PV Controller)
- Multi-Mode Inverter Controller
- Inverter Power Module(s)
- PFC Rectifier Controller
- Rectifier Power Modules



United Solar Systems



Design/Qualification of Field Applied PV Membrane

PV-BONUS 2 Subcontract
DE-FC36-98GO10249

1998 PV Performance and Reliability Workshop
November 3-5, 1998
Cocoa Beach, Florida

UNI-SOLAR

Field Applied PV Membrane

(aka: Roofing Laminates)

- PV Laminates Shipped in a Roll
- LM-SSR-60/120 and LM-ASR-60/120
- Best Delivered Price
- Local Added Value
- Sales Agreements
  - Warranty Terms (at Solder Tabs)
  - Bonding and Termination Technology
  - Shared Application Methods

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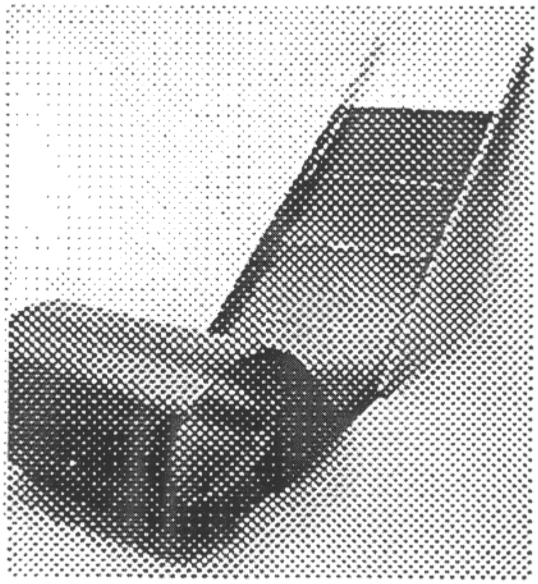
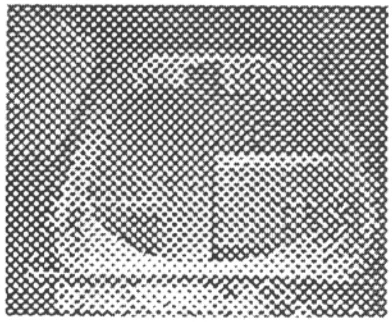
UNI-SOLAR PV ROOFING LAMINATE



Roll Shippable



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Field Applied PV Membrane

PV-BONUS 2 Program

- Focused Markets
  - Commercial Flat Roofs (Retail/Chain Stores)
  - Covered Parking/Shelters (Airport, Schools)
  - Sloped Metal and Tile New Construction
- 5 MW Business Goal
  - 1000 Systems at 5 kWac (nom.)
  - $ 24,995.00 per system
  - $ .15-.20/kWh Distributed Clean Generation
- Market Channels
  - ESCO (sales and financing)
  - System Integrator (hardware, install, and service)

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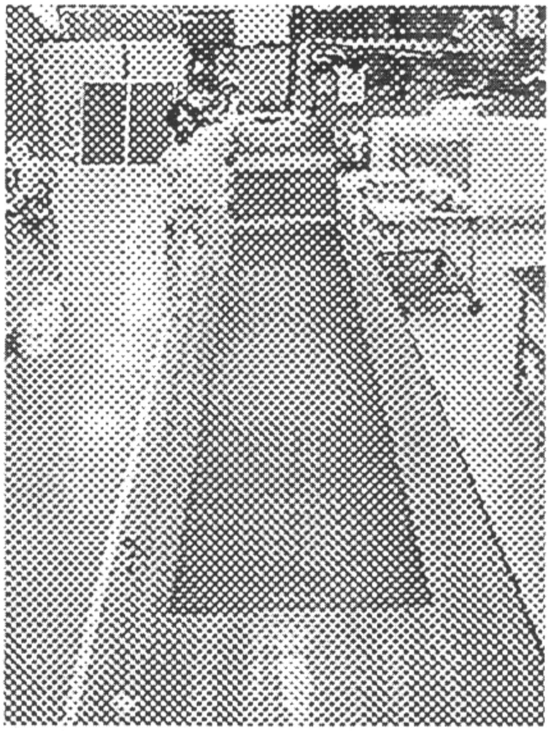

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Program Goals

- Develop Field Applied PV Membrane to Reduce the Costs of Building Integrated PV Systems, Expand Markets and Develop Alliances
- Achieve $25 million, 5 MW Business in 5 years
- Form Alliances with ESCO's & Their Customers

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Key Tasks and Milestones

- Product Development and Testing
  - Final Design, Roof/Building Interface Issues, Systems Design, Installation, Fabrication, Standard Designs, R&D, Production, Test/Acceptance Plan, ID Resources
- Market Development
  - Cost/Price Analysis, Market Entry Strategy, Education/Training, Demos
- Business Development

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Product Development/Testing

- Final Design/Roof Building Interface
  - Backing (Tedlar, Nylon, etc)
  - Bonding (EVA/Hotplate, Scotchweld)
  - Roof/Building Interface
    - » Flat Commercial Roofs
    - » Covered Parking - R Deck and similar
    - » Field Bonded to SSR and ASR Metal Roofing
    - » Tile/Shingle Application
  - Termination and Wiring Protection
    - » Multi-Contact & Wireway
  - Qualification (UL, IEEE, BOCA/ICBO)
    - » UL Review Underway

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Systems Design

- Inverter Survey
  - Trace Technologies, Trace, Omnion
  - Design Operating Voltage Ranges
  - Power, Price and Volume
- PVM Electrical Specs
  - Cells in Series, PVM Characteristics
- Array Layouts (String/Array Building Blocks)
  - 5 kWac
  - 100 kWac

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System Installation/Fabrication

- On Site
- Roofers Training
  - Manuals and Training (Cornell)
  - NRCA
- Electrician
  - IDEW
- Startup

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Test/Acceptance Plans

- UL/IEEE/ISPRA, Building Codes
- Trade Acceptance Management & Training
  - United Union of Roofers,....
  - IBEW
  - NEC
- System Acceptance Plans
- O & M Contract Structure

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Market Development

- Alliances/Subcontracts
  - PGE ES, Onsite, SCE, LADWP, APS, Phasor
  - Samples and Preliminary Design Packages
    - » (PVM, Bonding, System Layouts, Costing)
- Cost / Price Analyses
  - (DTE/SSOE)
- Market Entry Strategy
- Education / Training
- Demos (Hawaii, Phoenix, Virginia)

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BOS AND SYSTEMS

November 4, 1998

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National Center for Photovoltaics

PV Performance and Reliability Workshop

BOS and Systems Sessions

Introduction - Chris Cameron, Sandia

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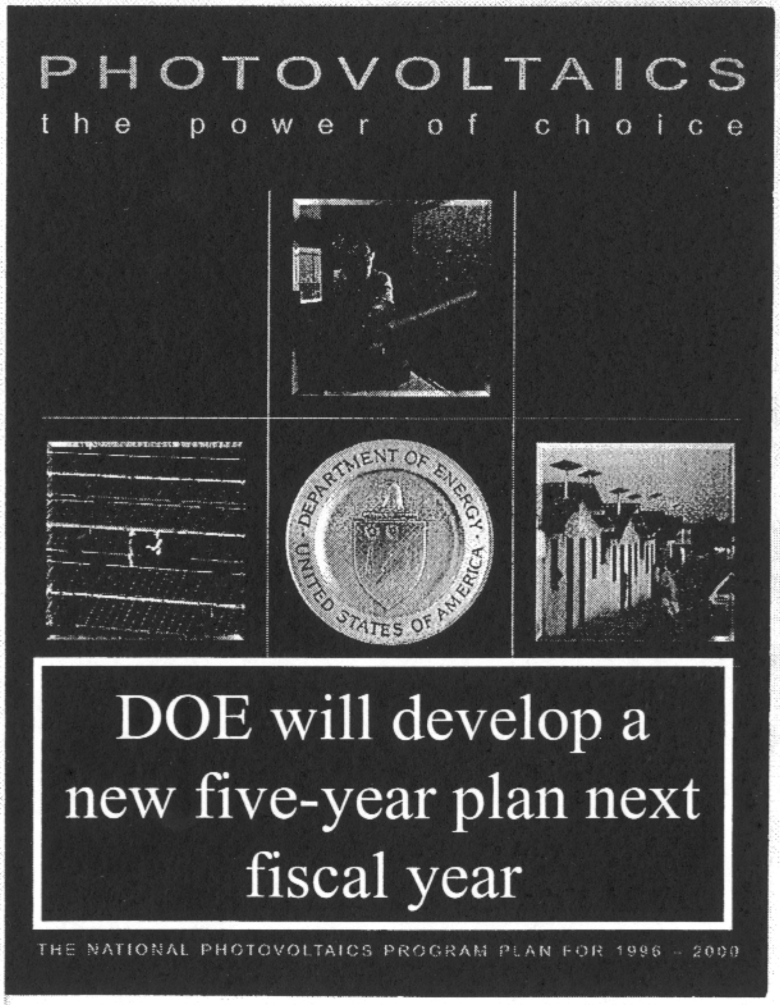

In preparation, **Technology Roadmapping** will be done this fiscal year:

- Technology Roadmapping is a **needs-driven** technology planning process to help **identify, select, and develop** the technology alternatives to satisfy a set of product needs

Must involve industry

NEED - For Markets to Expand, PV Must Be a Better Value, More Accessible Alternative

- Best Economic Choice - *Costs Less*
  - Power wherever the sun shines
    - Alternatives include a wire, pipeline, or road
- Better *value* - something worth paying for
  - Cleaner, quieter, unaffected by storms, spill-free...
  - ***Greener*** - intangible value - same electrons
    - a marketplace analogy is ***dolphin-safe tuna***
- Only marginally harder to access than what we currently use

National Center for Photovoltaics

Cost must decrease, value increase, ease of access must improve

- **We must know where we need to go**
  - What are cost, value, and access targets?
- **To get to those targets, we must**
  - Know where we are
  - Have an understanding of how we got here
    - what worked or did not work
  - Address needs with right tools
    - R&D, sustainable infrastructure, leverage parallel development

NREL National Renewable Energy Laboratory

Sandia National Laboratories
A partner in the National Center for Photovoltaics

Learning curve has been 82%

(When production doubles, cost drops 18%)

- Modules dominated - will other costs drop as fast?
- How will installed system cost drop?
  - e.g. efficiency affects installed cost - not in $/W metric
  - PV building elements might offset cost - increase value
- How can maintenance costs be reduced?
  - Module reliability is expected, but minimal investment in reliability has been made elsewhere
  - Other cost issues: service infrastructure, reroofing…
  - If target $0.01/hWh for maintenance ~ $25/kW/yr (ABQ)

Some Goals for Meeting

- Share lessons learned and new developments
- Set the stage for industry involvement in technology roadmapping & five-year plan
  - Improve understanding of where we are and where we need to go
- Set the stage for next year's workshop
  - Identify key development needs that can be worked on collectively
  - Identify potential topics for focused interactive sessions

National Center for Photovoltaics

MAINTAINING PV SYSTEMS

Michael Thomas
Sandia National Laboratories

National Center for Photovoltaics

Todays Theme

- Identifying the wholes in our databases.
- The Performance and Reliability workshop is all about evaluating the cost and benefit of PV systems
  - Focus on installed hardware costs has left us with lots of questions

Technology Issue - Recurring Costs

- Maintenance and capital replacement vary widely from system to system
- Little quantitative information available
- Metric of $/kWh for maintenance potentially useful for grid-tied systems only

Status Summary

- Based on 20 years of Field Experience
- On-going analysis
- Definition of System "Lifetime"
- Recurring costs are ill-defined
  - capital replacement costs
  - scheduled maintenance
  - repair and emergency service (unscheduled

Two Qualified Databases

- 90 small systems in the Colorado State Parks
  - 3 yrs of information on half, ~1 yr on half
  - all operational
- Three Dozen Systems installed in the 1980's
  - 25% now operating
  - some re-deployed. Some hardware sold

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- Maintenance concepts for PV systems greater than 1 MW. Grid-connected
- No personnel on site.
- One-day response to power-processing alarms.
- Check sub-fields periodically when on-site
- PV modules not checked

Communications application—5kW - $100K. Remote site. Generator seldom operates. Batteries seldom receive deep discharge.

Assumptions	Hi	Lo
Labor cost is $30/hour		
Routine maintenance	$1440/yr	$1440/yr
2 calls/yr, 2 persons, 2 days, 12 hours per call, generator oil changes covered in calls.		
Battery replacement	8 years	10 years
Controls replacement	10 years	15 years
Engine replacement	Once	None
PV augmentation	1kW, year 10	None

Village power application—50kW - $500K. Accessible site. Average load is 10 kW for 240 kWh daily energy requirement. Peak load is 40 kW. Engine generator produces 60% of energy for the load; operates 6 hours per day, 2200 hours annually.

Assumptions	Hi	Lo
Labor cost is $30/hour		
Routine maintenance	$12,000/yr	$12,000/yr
100 calls/yr,		
4 hours per call,		
generator oil changes covered in calls.		
Battery replacement	4 years	8 years
Inverter replacement	10 years	15 years
Engine replacement	Once	None

Lessons Learned

- Demo systems leave an unpleasant legacy - when not based on revenue
- Hardware replacement costs likely to be 2-4 times routine maintenance
- Maintenance of PV/Hybrid 20-40 times less than engine, but not necessarily of higher value

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Colorado Parks

- Average Installed cost per system about $1200
  - $100 repair, $100 labor/sys/yr
  - $50/yr/system capital replacement
  - $250/yr/sys total- 21%/yr of installed
- Vandalism represents 40% of total
- Controllers are Hardware Problem
  - 7%/yr for on-off- 3 years; 8%/yr for PMW - 1 year

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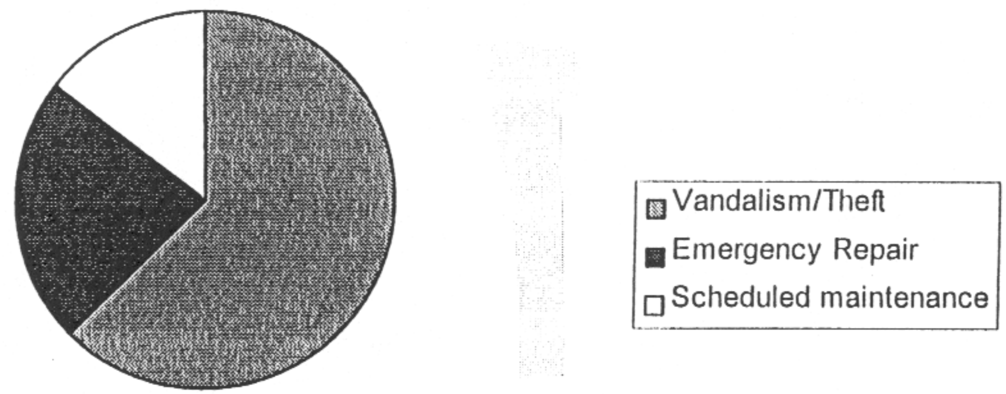
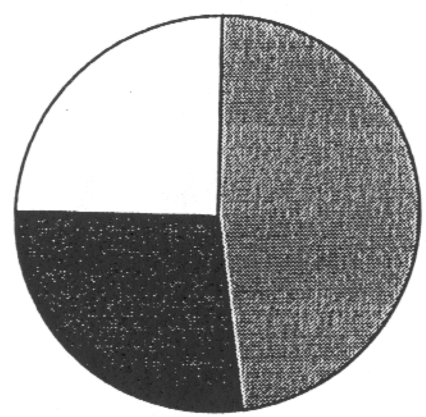
Colorado Parks

DC Systems - Maintenance Cost Breakdown



DC Systems - Labor Time Breakdown



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Attention Areas

- **Make Hardware Invisible**
  - use low profile to hide panel on roof
  - mount out-of-site if possible
  - minimize No. and size of modules
- **Make system Inaccessible**
  - Use Tamper resistant hardware & slippery pole
  - Weld panels in place
  - store off-site at end of season

FLORIDA SOLAR ENERGY CENTER

A Research Institute of the University of Central Florida

Florida Photovoltaic Buildings Program

1998 Photovoltaic Performance and Reliability Workshop

Jerry Ventre

November 3-5, 1998

Small Utility-Interactive Photovoltaic Systems

- Approximately a thousand utility-interactive rooftop systems in the U.S. today.
- SMUD is the most experienced U.S. utility with rooftop PV systems, with over 400.
- The U.S. announced a Million Solar Roofs Initiative (MSRI) in June 1997:
  - In response to Japanese and European initiatives.
  - Goal is one million solar (photovoltaic, DHW and pool heating) installations by 2010

To develop a market for PV buildings, the following must occur:

- Prices must be reduced
  - module costs
  - non-module costs
  - operation and maintenance costs
- Appropriate interconnection requirements must be established
- Other issues and barriers must be addressed
  - mobility
  - performance and reliability issues

Interconnection Issues

- Technical
  - Safety
  - Equipment protection
  - Power quality
  - Reliability of service
- Policy
  - Precedence
  - Liability
  - Competition, deregulation, etc.
  - Other

What are appropriate interconnection requirements?

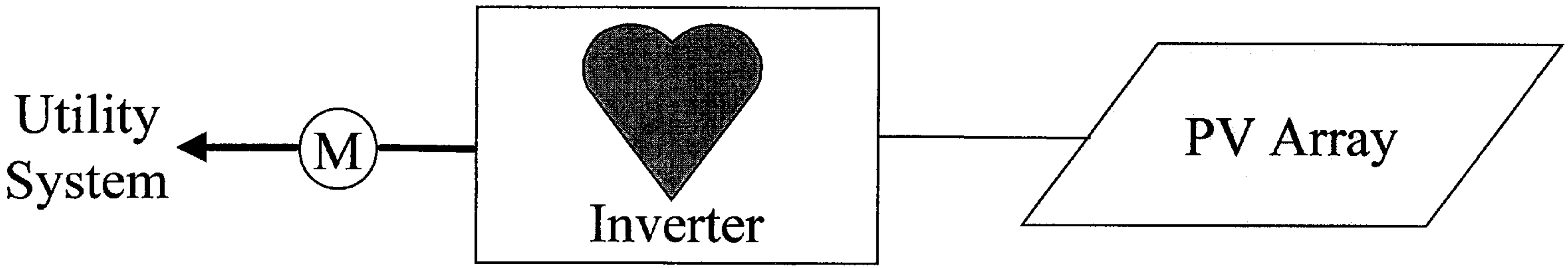
- The interconnected PV system poses no serious safety or reliability problems to the utility or its customers.
- The process of interconnecting a small PV system is routine.
- The process is fair.
- The process is expeditious.
- The process provides utility customers with the freedom to choose renewable energy.

Purpose of IEEE P929

"This recommended practice contains guidance regarding equipment and functions necessary to ensure compatible operation of photovoltaic systems with the electric utility. This includes factors relating to personnel safety, equipment protection, power quality and utility system operation."

- Power Quality
- Safety and Protection

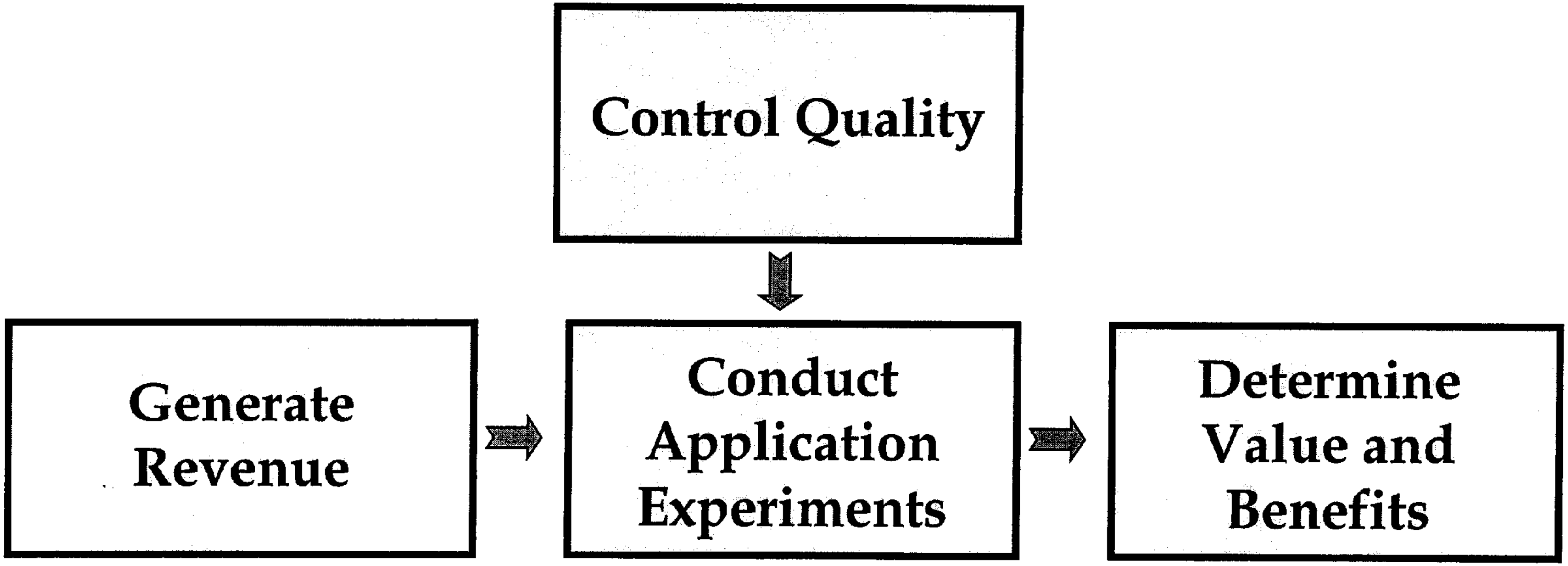
What does IEEE P929 really impact?



Florida's Response to MSRI

- Florida Photovoltaic Buildings Program
  - Application experiments to determine value and benefits, with emphasis on quality control.
  - Nine end user groups.
- Florida Photovoltaic Buy-Down Program
  - $525k for systems, $75k for monitoring.
- Statewide Green Pricing Initiative
- FSEC PV Technical Support Program

Florida Photovoltaic Buildings Program



FSEC offers the following PV technical support services:

- Identify applications
- Support projects
- Survey sites
- Develop specifications
- Buy down costs
- Review designs
- Train personnel
- Test components
- Predict performance
- Accept installations
- Monitor performance
- Inspect systems
- Assess value
- Publish results

What do we need to know?

- Impact of distributed generation on utility operations
- Value of distributed generation as a future business opportunity
- Relationship between distributed generation and load management strategies
- Extent to which non-module costs can be reduced

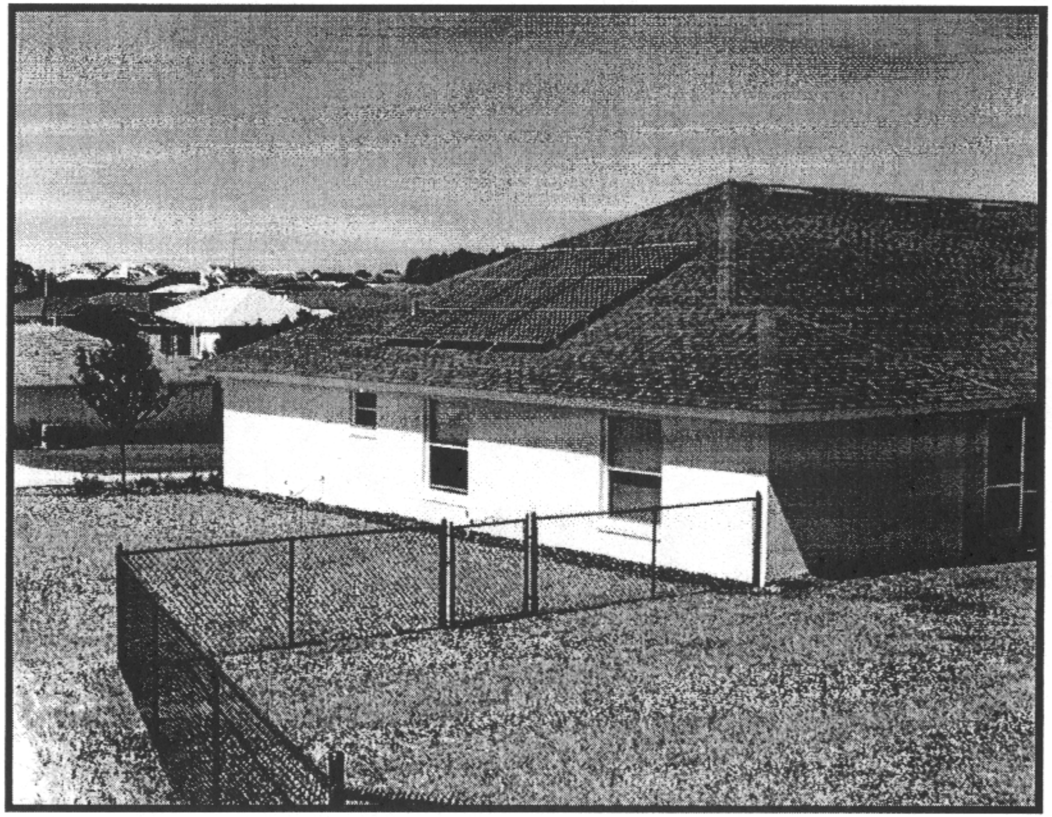
What do we need to know? (cont.)

- Most effective combinations of building energy efficiency and PV generation
- Recommended designs for fault and weather tolerant buildings
- Better ways of integrating PV materials into buildings
- Performance and reliability of alternative inverter configurations

PV Building Application Experiments for Nine End User Groups

Application Experiments / End-user Groups	Distributed generation	Community developments	PV and energy-efficient buildings	Fault and weather-tolerant buildings	Durable array-roof configurations	Arrays laminated onto metal roofing	Building-integrated PV	Factory installed PV systems	Alternative inverter configurations
Municipal utilities and rural electric cooperatives	x	x							x
Commercial building owners and operators			x	x			x		
Government and public agencies					x	x		x	
School and church organizations						x		x	x
Manufactured building corporations			x				x	x	
Investor-owned utilities	x	x							x
Commercial roofing companies					x	x	x		
Builders and developers		x	x	x					
Homeowners and buyers			x	x	x				

Distributed Generation



- Effects on utility operations
- Time value of PV production
- Sufficient information for business planning

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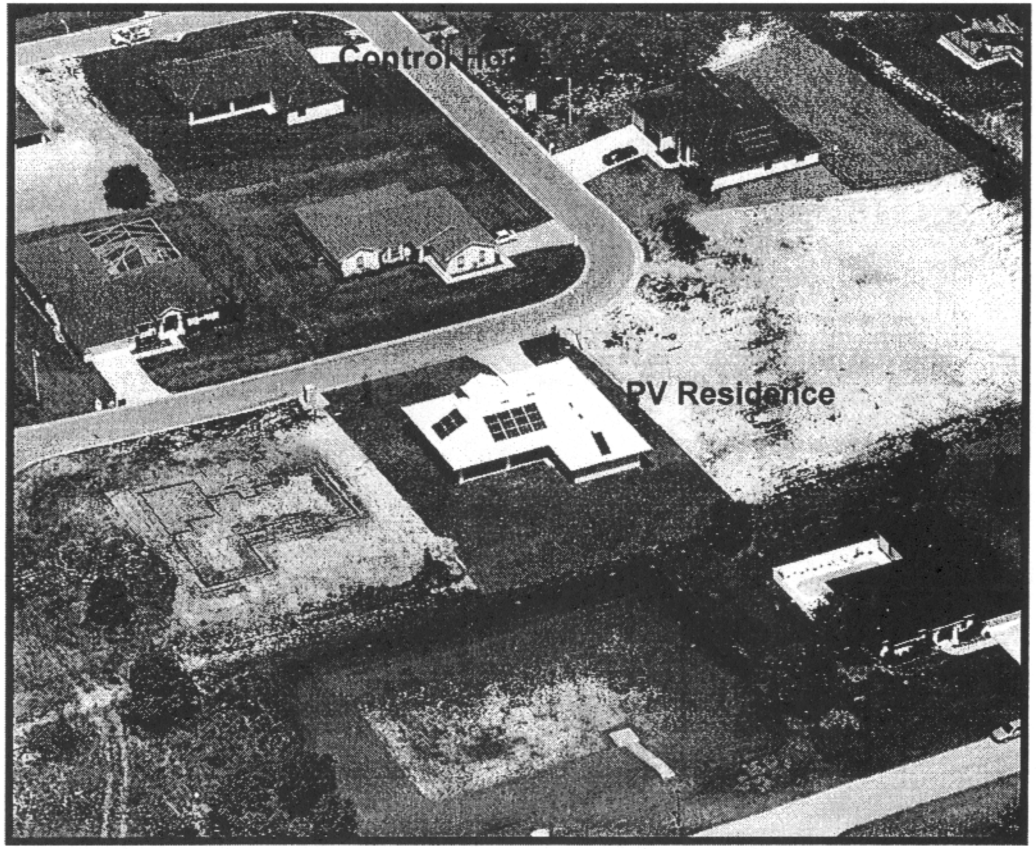
Community Developments

- Synergism between building energy efficiency and load management
- Marketability of green communities
- Manufactured building community



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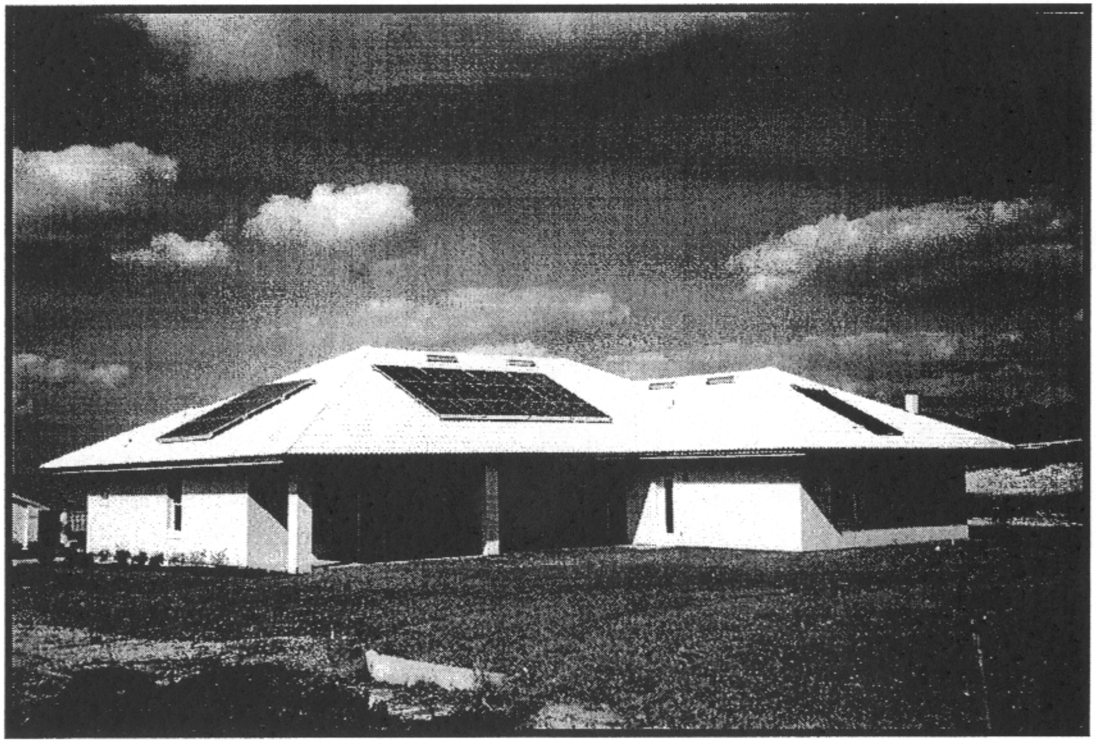
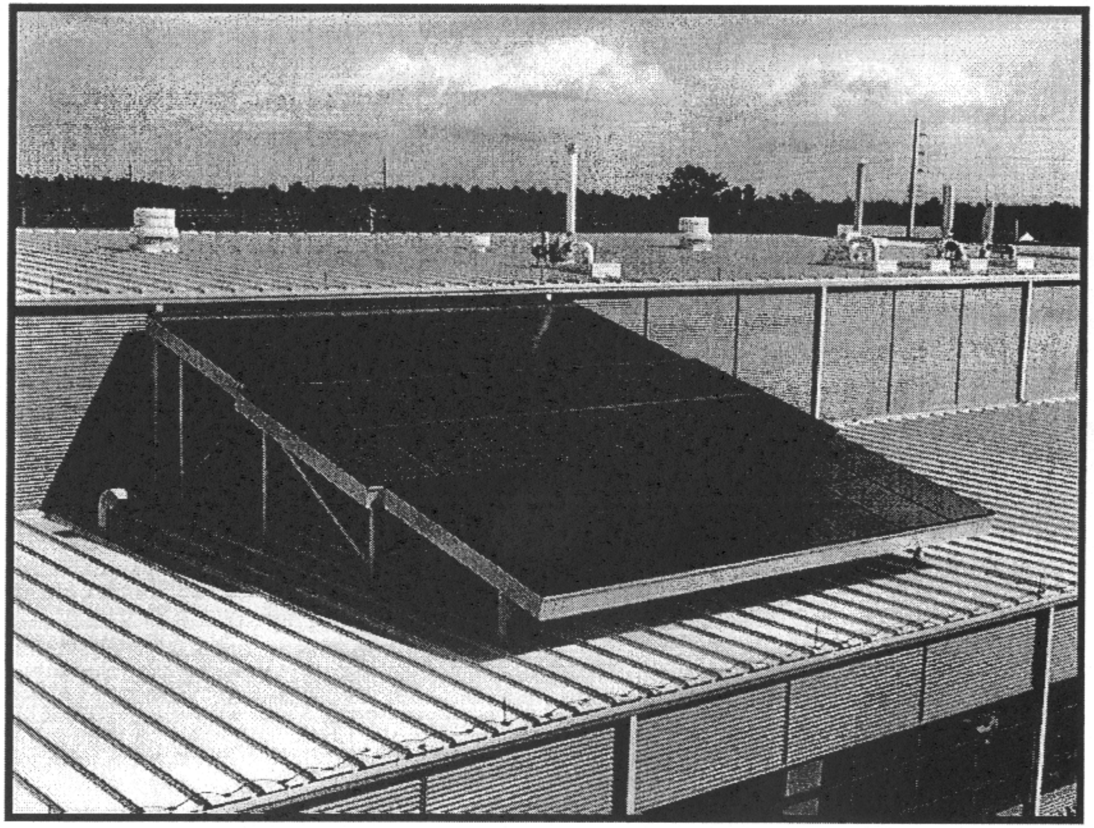
PV and Energy Efficient Buildings

- Most effective combinations of building energy efficiency and PV production
- Marketability of energy efficient PV buildings
- Building energy management



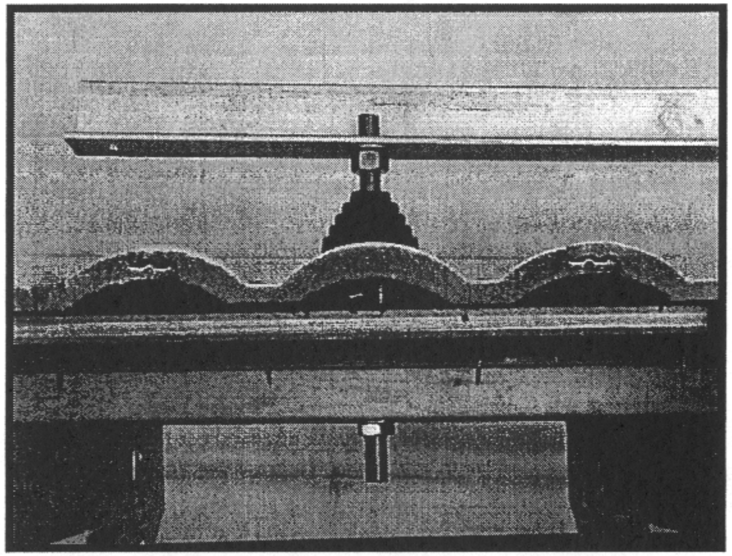
Fault and Weather Tolerant Buildings

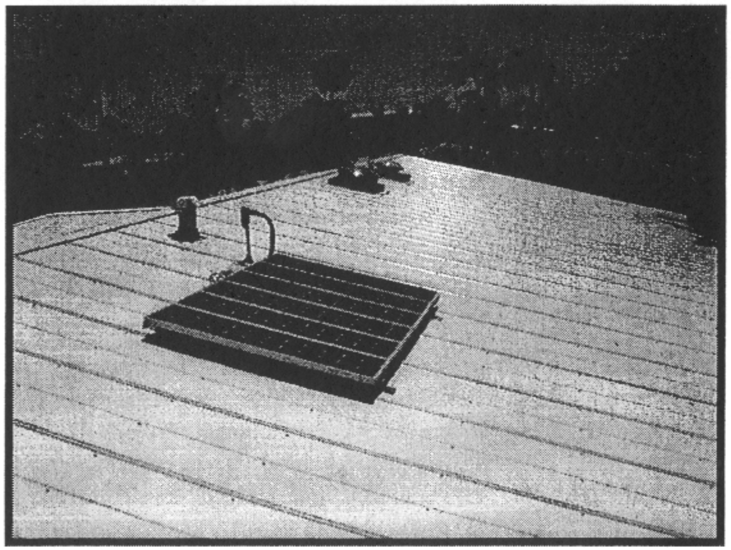
- Marketability of uninterruptible building power systems
- Economic and performance trade- offs
- Integration into hurricane tolerant buildings



Durable Array-Roof Configurations

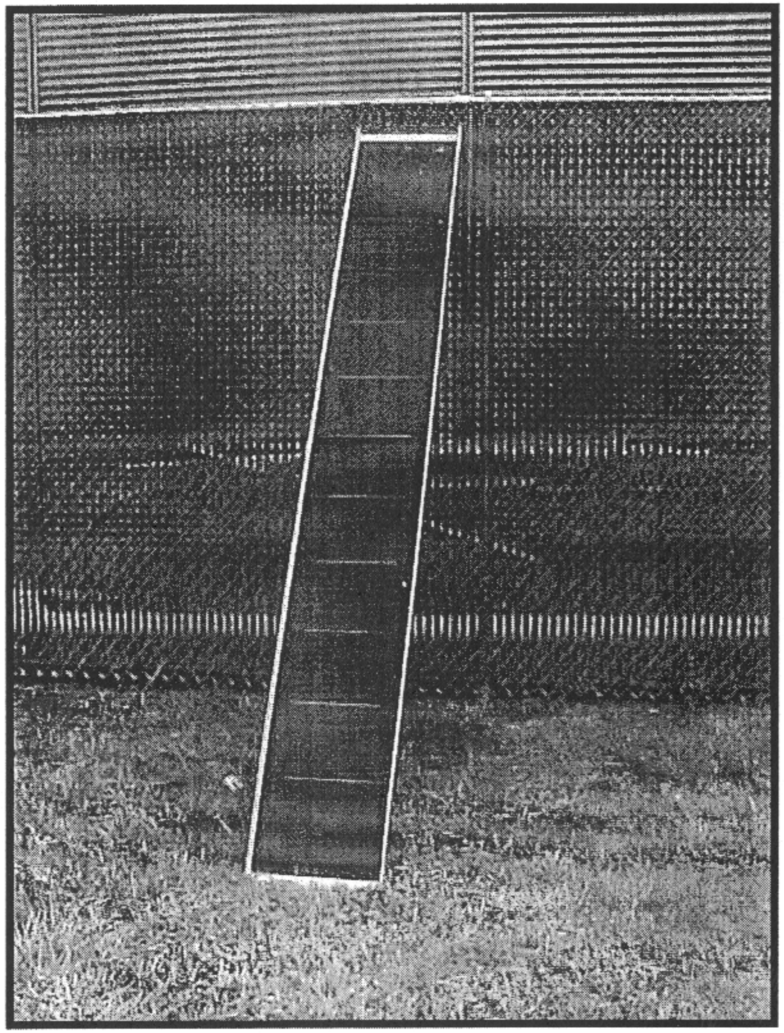
- Standoff arrays on metal roofs
- Standoff arrays on tile roofs
- Life-cycle analyses of durable array-roof configurations





Arrays Laminated onto Metal Roofing

- On-site and proximity lamination
- Performance evaluations and economic analyses
- Assimilation of lamination process into warehouse operations



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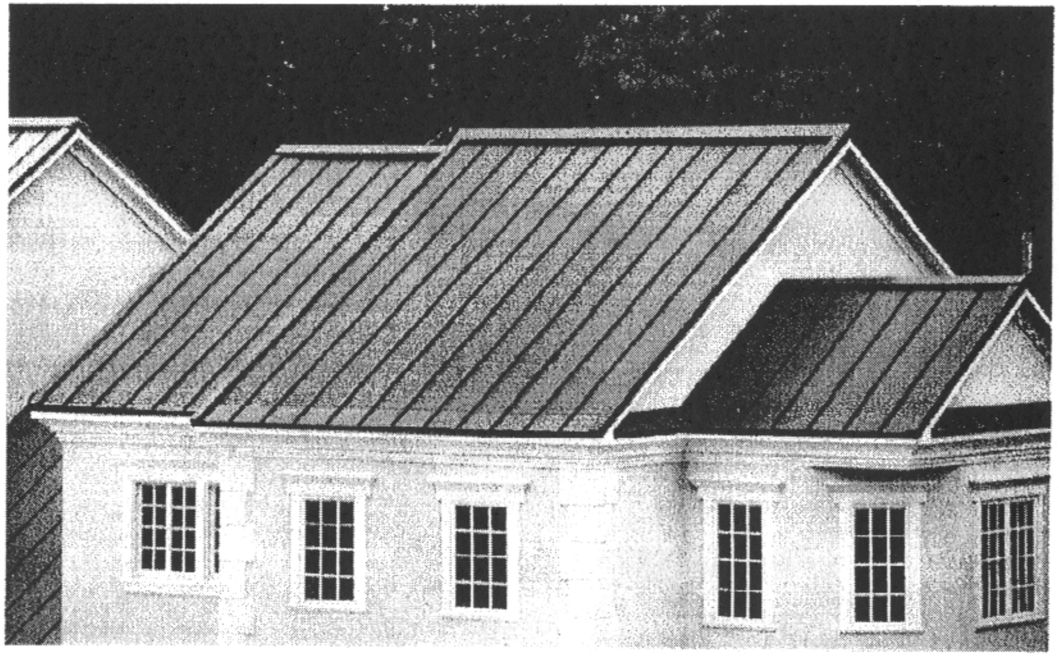
Building Integrated Photovoltaics

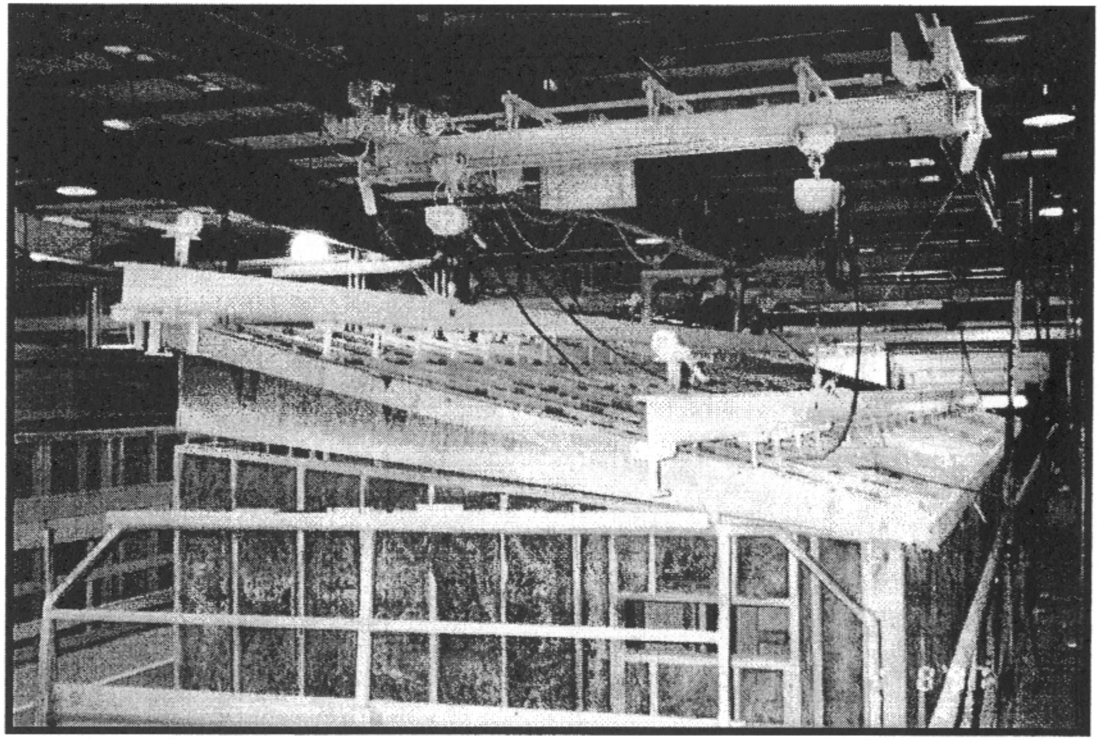
- Replacing building materials with PV products
- Evaluating installation processes
- Economic Analyses
- Marketability of aesthetically pleasing designs



Unisolar Roofing, United Solar Systems Corporation

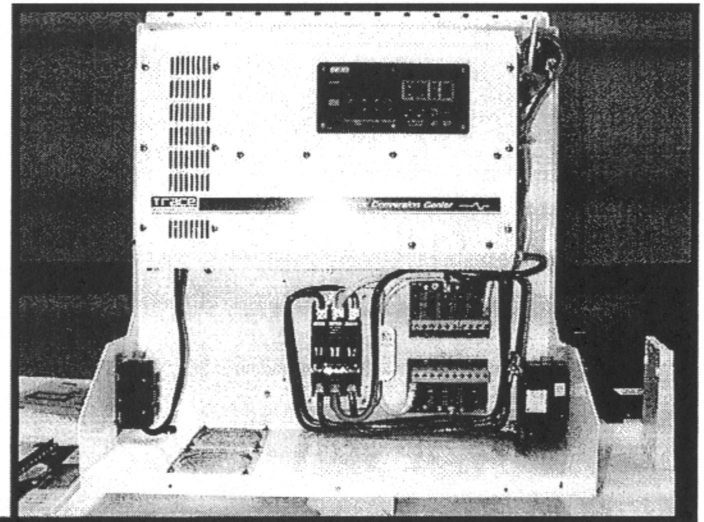
Factory Installed PV Systems

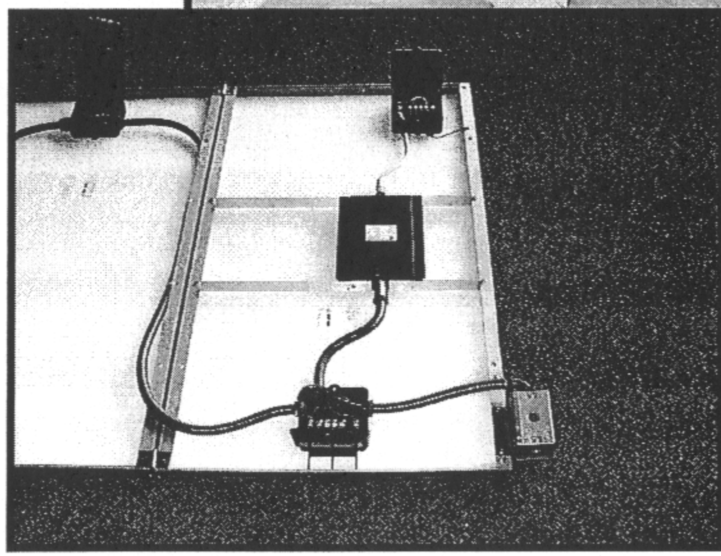
- Complete or partial installation in a factory environment
- Reducing installation costs
- Improving quality control



Alternative Inverter Configurations

- Evaluation of micro-inverters in hot, humid climates
- Evaluation of multiple arrays feeding a single inverter
- Special experiments to support reasonable interconnection requirements





STATUS

IEEE STANDARDS COORDINATING COMMITTEE

(SCC21)

and

IEC STANDARDS TECHNICAL COMMITTEE 82

(TC82)

by

Richard DeBlasio
November, 1998

HIGHLIGHTS

IEEE SCC21

IEEE SCC21 NEW SCOPE AND MISSION

INITIATED PV SYSTEMS TESTING PROJECT P1526

P1374 (SYSTEM SAFETY) PUBLISHED

P929 ABOUT TO BE BALLOTED BY SCC21

NEXT SCC21 MEETING, 12/9-11/98, WASH. DC

IEEE STANDARDS COORDINATING

COMMITTEE 21

for

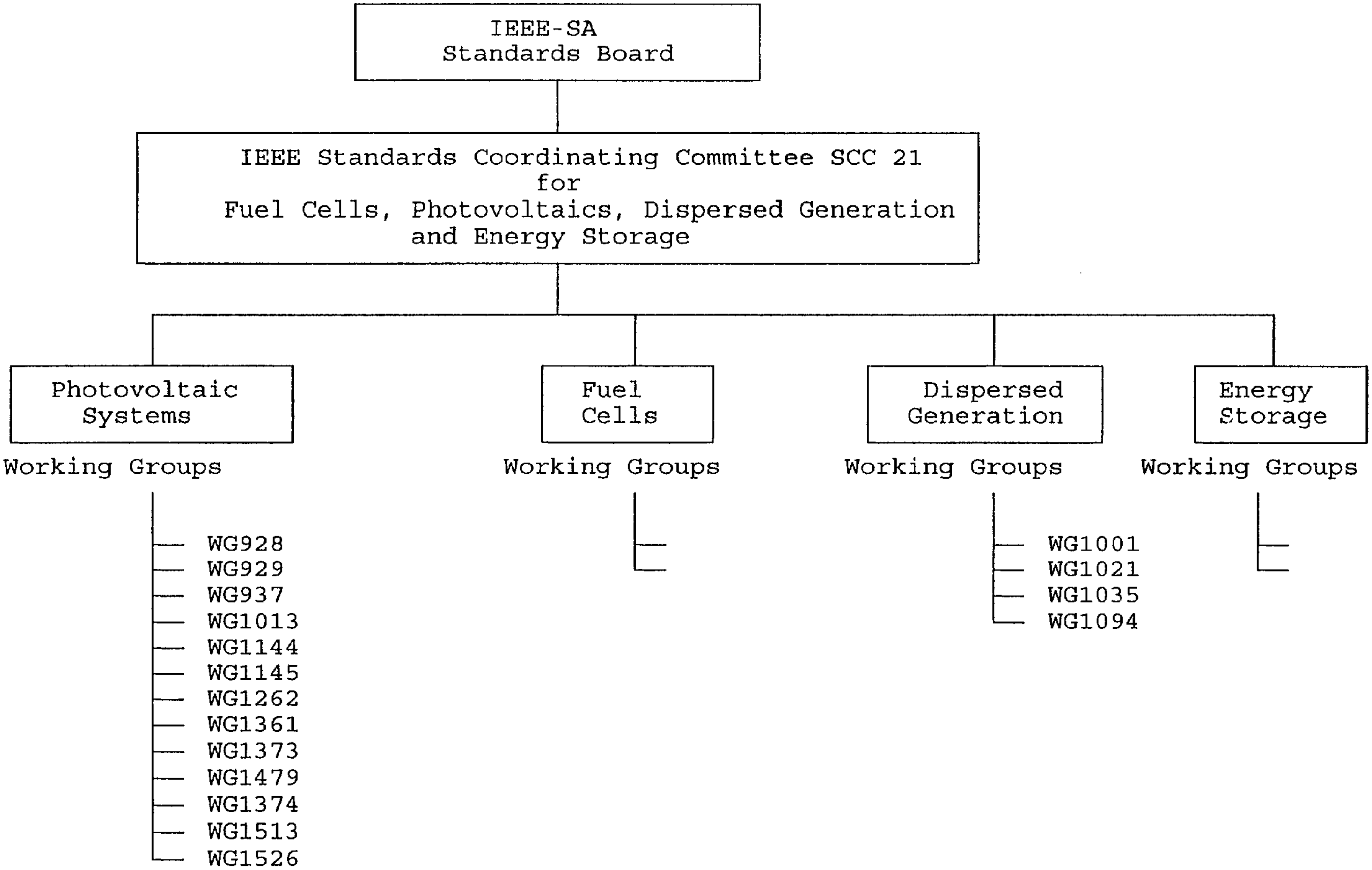
Fuel Cells, Photovoltaics, Dispersed Generation,
and
Energy Storage

IEEE SCC21 SCOPE

Oversees the development of standards in the areas of Fuel cells, Photovoltaics, Dispersed Generation, and Energy Storage, and coordinates efforts in these fields among the various IEEE Societies and other affected organization to insure that all standards are consistent and properly reflect the views of all applicable disciplines.

Reviews all proposed IEEE standards in these fields before their submission to the IEEE-SA Standards Board for approval and coordinates submission to other organizations.

Approved by the IEEE Standards Board on June 25, 1998.



New IEEE SCC21 Scope: Oversees the development of standards in the areas of Fuel Cells. Photovoltaics, Dispersed Generation, and Energy Storage, and coordinates efforts in these fields among the various IEEE Societies and other affected organizations to insure that all such IEEE standards are consistent and properly reflect the views of all applicable disciplines. Reviews all proposed IEEE standards in these fields before their submission to the IEEE - SA Standards Board for approval and coordinates submission to other organizations. (Approved by the Board during the June 1998 meeting) R. DeBlasio

IEEE-SA STANDARDS COORDINATING COMMITTEE SCC21

MEMBERSHIP ROSTER

IEEE SA SCC21 Chairman:	Richard DeBlasio (6372692)
IEEE SA SCC21 Vice Chairman:	Steve Chalmers (3398609)
IEEE SA SCC21 Secretary:	Jerry Anderson ( )
Working Group Chairman:	(S.Chalmers, J.Stevens, J. Chamberlin, J. Wohlgemuth, C. Whitaker, J. Wiles, B. Kroposki, R. McConnell)
Liaison Members:	(R. Feero, C. Osterwald, J. Anderson, S. Chalmers, W. Bower, J. Chamberlin, D. Dawson, B. Hornberger, J. Smyth, K. Hetch, D. Conover, J. Koepfinger)

IEEE SA SCC21 Working Groups and Chairman

<u>Photovoltaics</u>

Steve Chalmers (3398609)	IEEE 928
John Stevens (5943170)	IEEE 929, P929
Jay Chamberlin (0139956A)	IEEE 937, P937, IEEE 1013, P1013, IEEE 1144, IEEE 1145, P1145, P1361
John Wohlgemuth (2919876)	IEEE 1262
Charles Whitaker (1712926)	P1373
John Wiles (1007442)	P1374
Ben Kroposki (0636670)	P1526, P1479
Robert McConnell (02770683)	P1513

<u>Dispersed Storage</u>

TBD	IEEE 1021
TBD	IEEE 1001
TBD	IEEE 1035
TBD	IEEE 1094
Task Force (PES/PSRC)	

<u>Fuel Cells</u>

TBD
Task Force (PES/EDPGC/EDSC)

<u>Energy Storage</u>
TBD

IEEE-SA STANDARDS COORDINATING COMMITTEE SCC21 (Continued)

IEEE SA SCC21 Liaison and Representatives Roster

R. Feero	(IEEE PES/PSRC) Task Force
C. Osterwald	(ASTM E 44.09)
J. Anderson	IEC/TC82
S. Chalmers	IEC/TC82 U.S. TAG (Technical Advisory Group), PowerMark, PVGAP
W. Bower	NEC/CMP-3 Technical Committee
J. Chamberlin	SCC29
D. Dawson	SCC23
B. Hornberger	IA/ESC (Industrial Applications/Energy Systems Committee)
J. Smyth	UL (Underwriters Laboratory, Inc.)
K. Hetch	(IEEE PES/Energy Development and Power Generation Committee/Energy Development Subcommittee) Task Force
D. Conover	IEC ad hoc Group on Fuel Cell Power Plants
J. Koepfinger	IEEE Standards Board - Fuel Cells Coordination
TBD	Energy Storage

IEEE SCC21 Standards and Status

Number	Title	Status
928	IEEE Recommended Criteria for Terrestrial Photovoltaic Power Systems	Printed 1986 Reaffirmed 1991 Reaffirm by 5/2000
929	IEEE Recommended Practice for Utility Interface of Residential and Intermediate Photovoltaic Systems	Printed 1988 Reaffirmed 1991 Reaffirm by 5/2000
P929	Recommended Practice for Utility Interface of Photovoltaic (PV) Systems	PAR* approval 9/96 work in progress
937	IEEE Recommended Practice for Installation and Maintenance of Lead Acid Batteries for Photovoltaic Systems	Printed 1987 Reaffirmed 1993
P937	Installation and Maintenance of Lead-Acid Batteries for (PV) Systems	work in progress Planned Completion 2002
1013	IEEE Recommended Practice for Sizing Lead Acid Batteries for Photovoltaic Systems	Printed 1990

P1013	Recommended Practice for Sizing Lead-Acid Batteries Photovoltaic (PV) Systems	work in progress Planned Completion 2002
1144	Sizing of Industrial Nickel Cadmium Batteries for Photovoltaic Systems	Printed 1987 Reaffirmed 1996
1145	IEEE Recommended Practice for Installation and Maintenance of Nickel Cadmium Batteries for Photovoltaic Systems	Printed 1991
P1145	Recommended Practice for Installation and Maintenance of Nickel-Cadmium Batteries for Photovoltaic Systems	work in progress Planned completion 2002
1262	Recommended Practice for Qualification of Photovoltaic Modules	Printed 1996
P1361	Recommended Practice for Determining Performance Characteristics and Suitability of Batteries in Photovoltaic Systems	PAR* approval 1993 work in progress Planned Completion 2000
P1373	Recommended Practice for Field Test Methods and Procedures for grid-Connected Photovoltaic Systems	work in progress Planned Completion 1999

P1374	Guide for Terrestrial Photovoltaic Power System Safety	Printed 1998
P1479	Recommended Practice for the Evaluation of Photovoltaic Module Energy Production	work in progress Planned Completion 1998
P1513	Recommended Practice for Qualification of Concentrator Photovoltaic (PV) Receiver Sections and Modules	work in progress Planned completion 2001
P1526	Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems	work in progress Planned completion 2002

* (Project Authorization Request to the IEEE Standards Board)

NEXT IEEE SCC21 MEETING

DECEMBER 9-11, 1998

WASHINGTON, DC

HIGHLIGHTS

IEC TC82

MEETING HELD IN DENMARK

MAY 21-25, 1998

(47 PARTICIPANTS-13 MEMBER COUNTRIES)

INITIATED BOS WG 6

INITIATED QUALITY/CERTIFICATION WG 5

24 IEC STANDARDS PUBLISHED

INTERNATIONAL PHOTOVOLTAIC STANDARDS

ANSI*	USNC**	IEC***
	U.S. Technical Advisor	TC-82 Photovoltaics
	U.S. Technical Advisory Group (TAG)	Chair: U.S.A. Secretariat: U.S.A.
		Working Groups
		Glossary
		Modules---Systems--- Quality and Certification ---Balance of Systems
		Proposed WG---Concentrators---Storage---Environmental/Mechanical

* American National Standards Institute
** United States National Committee
*** International Electrotechnical Commission

IEC TC-82 Standards and Status

Number	Title	Status
IEC-60891	Procedures for Temperature and Irradiance Corrections to Measured I/V Characteristics of Crystalline Silicon PV Devices	Printed
IEC-60904-1	Measurement of PV I/V Characteristics	Printed
IEC-96904-2	Requirements for Reference Solar Cells	Printed
IEC-60904-3	Measurement Principals for Terrestrial PV Solar Devices with Reference Spectral Irradiance Data	Printed
IEC-60904-4	On-Site Measurements of Crystalline Silicon PV Array I-V Characteristics	Printed
IEC-60904-5	Determination of the Equivalent Cell Temperature (ECT) of Photovoltaic (PV) Devices by the Open-Circuit Voltage Method	Printed
IEC-60904-6	Requirements for Reference Solar Modules	Printed
IEC-60904-7	Computation of Spectral Mismatch Error Introduced in the Testing of a PV Device	Printed
IEC-60904-8	Guidance for Spectral Measurement of Spectral Response of a PV Device	Printed
IEC-60904-9	Solar Simulator Performance Requirements	Printed

IEC-60904-10	Linearity Measurement Methods	Printed
IEC-61173	Overvoltage Protection for PV Power Generating Systems	Printed
IEC-61194	Characteristic Parameters of Stand-Alone PV Systems	Printed
IEC-61215	Design and Type Approval of Crystalline Silicon Terrestrial PV Modules	Printed
IEC-61345	UV Test for PV Modules	Printed
IEC-61277	Guide-General Description of PV Power Generating System	Printed
IEC-61646	Thin Film Terrestrial PV Modules - Design Qualification and Type Approval	Printed

Number	Title	Status
IEC-61701	Salt Mist Corrosion Testing of PV Modules	Printed
IEC-61702	Rating of Direct Coupled PV Pumping Systems	Printed
IEC-61721	Susceptibility of a Module to Accidental Impact Damage (Resistance to Impact Test)	Printed
IEC-61724	PV System Performance Monitoring-Guidelines for Measurement, Data Exchange and Analysis	Printed
IEC-61725	Analytical Expression for Daily Solar Profiles	Printed

IEC-61727	PV Characteristics of the Utility Interface	Printed
IEC-61829	Crystalline Silicon PV Array-On Site Measurement of I-V Characteristics	Printed
IEC-61836	Solar Photovoltaic Energy Systems-Terms and Symbols	Printed

National Center for Photovoltaics

National Electrical Code - 1999 Status and Overview

by

Ward Bower

Sandia National Laboratories - PV System Applications

Ph: 505-844-5206 ; FAX 505-844-6541

wibower@sandia.gov

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Presented to:

PV Systems Performance and Reliability Conference

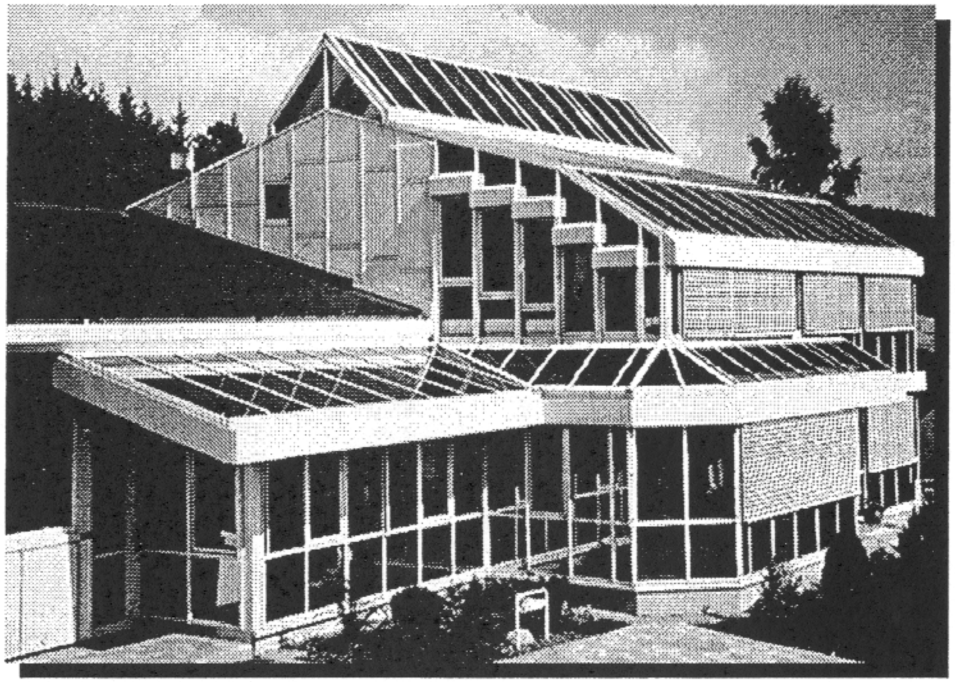
Cocoa Beach, FL - November 3-5, 1998

Introduction

- The Status of the NEC- 1999
- What's New in the NEC for PV
- National Electrical Code Revisions for 1999
- Where Do We Go From Here?

Need for the NEC for 1999

1954, Pearson, Chapin, Fuller at Bell Labs Produce a 6% X-Silicon PV Cell



We've Come A Long Way, Baby!

National Center for Photovoltaics

Status of the NEC for 1999

- The 57 Proposals that Were Submitted by the Task Group -Article 690- on behalf of the PV Industry Met with 100% Approval by Code Making Panel #3.
- Public Comments Supported Proposals With Only Minor Modifications.
- The 1999 NEC was published in September 1998.
- Changes in Article 250 (Grounding) or Other Articles May Affect Some PV installations.
- The NEC Work for the 1999 Code Cycle is Complete but The PV Industry Should Be Looking at Needed Changes for 2002.

Sandia National Laboratories
A partner in the National Center for Photovoltaics

National Center for Photovoltaics

What's New in the 1999 NEC

- Article 110 Part B - General Requirements for Over 600 Volts Has Been Expanded.
- Article 250 on Grounding has been Completely Reorganized. A Full Page Chart Leads Users Through This (Still-Complex) Article.
- Article 490 - Equipment Over 600 Volts Groups Material Moved From All Over the Code, Particularly Discontinued Art. 710.

National Center for Photovoltaics

What's New In Article 690

- New or Changed Definitions
- New Figure Identifying PV Components
- Ground-Fault Protection Expansion
- New AC PV Module Section
- Maximum System Voltage Includes a Table Correction Table and a 600V Limit for Dwellings

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What's New In Article 690

- Circuit Sizing and Current Calculations now Includes UL1703
- Exceptions for Overcurrent Devices
- New Stand-alone Section
- New Language for Marking AC Modules
- Point-of-Interconnection

What's New In Article 690

- Connection to Other Sources requires Identified Interactive Equipment and Automatic De-energizing
- Unbalance Connections Allowed
- Battery and Charge Control
- New Section (I) for Systems >600V

Where Do We Go From Here

- Proposals For the 2002 NEC Must be Submitted by November 5, 1999.
- Use and Review the 1999 Code.
- Note Code Deficiencies and Needed Changes.
- Submit Directly or Through Me.
- The Task Group Should Meet Once Before November 1999.

Utility PhotoVoltaic Group

Challenges for Wide-Scale Utility PV

Steve Hester
Technical Director

1998
Performance and Reliability Workshop
Cocoa Beach, Florida
November 3-4, 1998

Utility PhotoVoltaic Group

TEAM-UP

Highlights	Round 1 ($4/w)	Round 2 ($2/w)	Round 3 ($1.75/w)	Round 4 ($X/w)
UPVG Funding	$4.3 M	$ 5.6 M	$5.0 M	
Private Funding	$17.7 M	$18.4 M	$22 M	
Total Venture $	$22 M	$ 24 M	$27 M	
MW of PV	2.0 MW	2.6 MW	2.9 MW	
Number of Utilities	20	up to 30	>35	
PV Installations	170	1100	1200+	
# of States Involved	12	Up to 20	>25	

Utility PhotoVoltaic Group

TEAM-UP Status

- 47 UPVG Members Involved in *TEAM-UP*
- 2.6 MW Installed to Date
- Nearly 400 Systems installed

Grid-Independent Systems

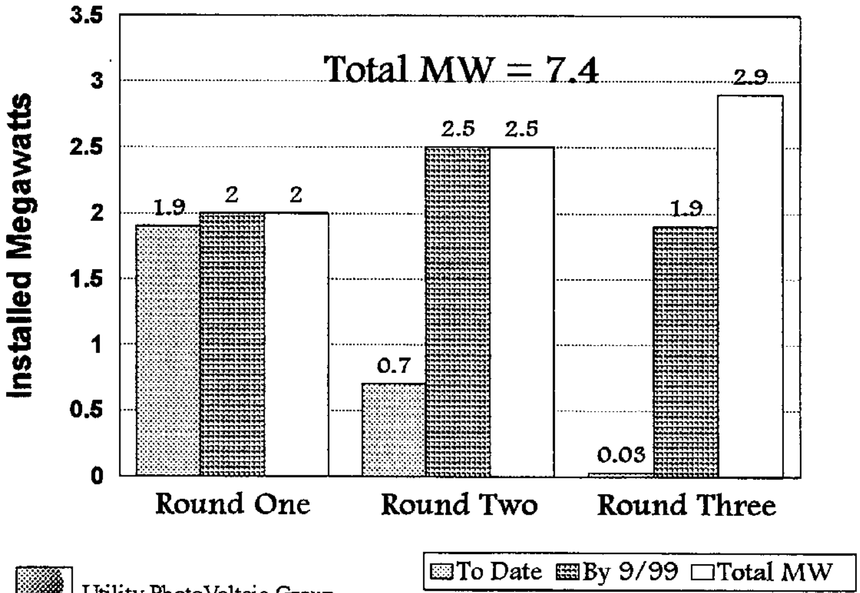
- 100+ are Grid-Independent

Grid-Connected Systems

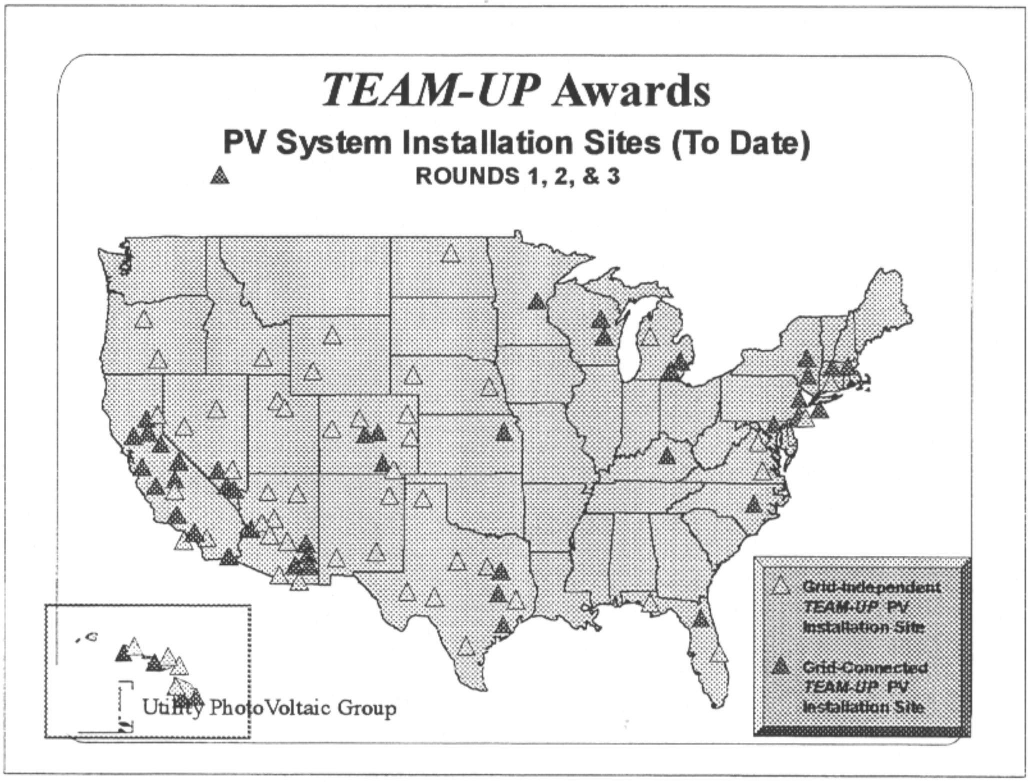
- Less than 20 are Ground-Mounted
- About 280 Rooftops Installed

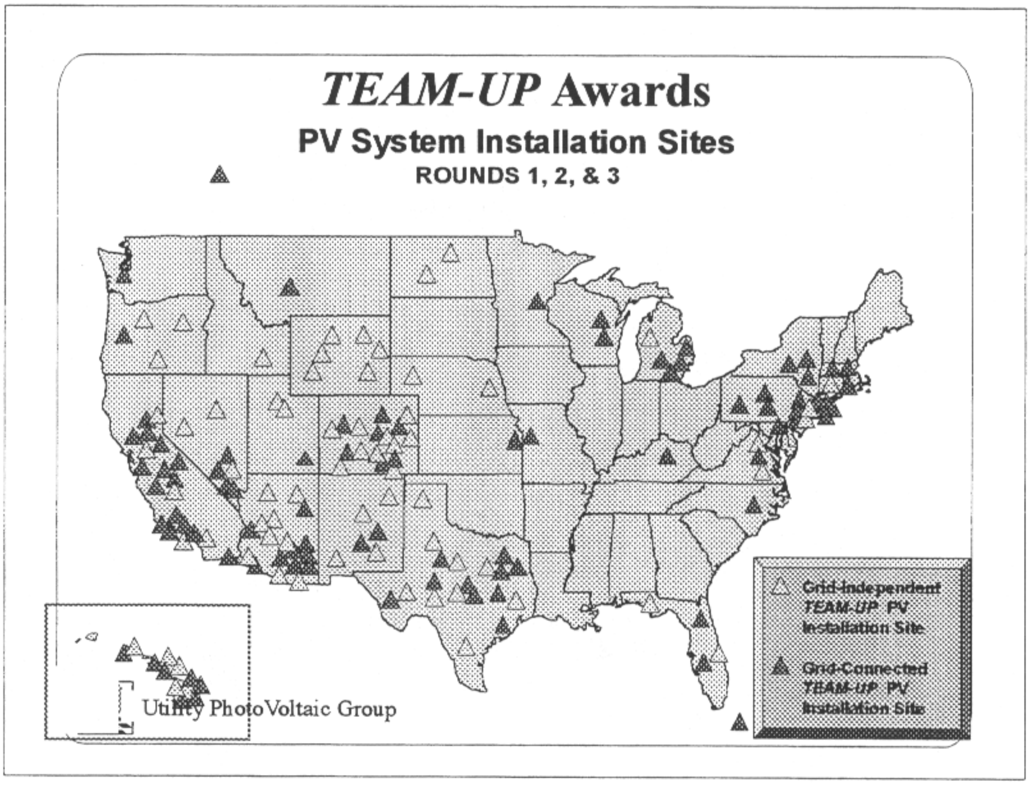
Utility PhotoVoltaic Group

TEAM-UP Venture Installations



Utility PhotoVoltaic Group


TEAM-UP Awards
PV System Installation Sites (To Date)
ROUNDS 1, 2, & 3
Grid-Independent *TEAM-UP* PV Installation Site
Grid-Connected *TEAM-UP* PV Installation Site
Utility PhotoVoltaic Group


TEAM-UP Awards
PV System Installation Sites
ROUNDS 1, 2, & 3
Grid-Independent *TEAM-UP* PV Installation Site
Grid-Connected *TEAM-UP* PV Installation Site
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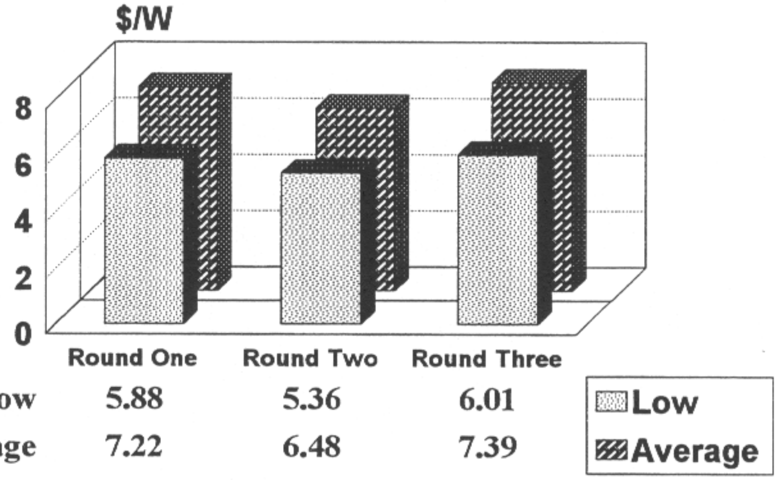
TEAM-UP PV System Prices

Installed System, Dollars per Watt



	Round One	Round Two	Round Three
Low	5.88	5.36	6.01
Average	7.22	6.48	7.39

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Observations

- Majority of the *TEAM-UP* systems are sold on the basis of "value" -- or -- cost per month........NOT ..... on a cents per kilowatthour !
- Almost all other "Consumer" products are sold on some "value" basis -- not -- least cost or cost-effective

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Observations

- TQM is not apparent
- Quality ______ missing on many ventures
- The value of QA/QC rarely understood
- Most QA/QC plans inadequate (two pages typical, and then usually just a parrot of what UPVG supplies)
- Acceptance test plans range from Good to Barely Adequate (two pages typical, and then usually just a parrot of what UPVG supplies)

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Observations

- Training for installers and inspectors should be expanded (PVUSA)
- Module reliability very good due to demand for the IEEE 1262 and UL requirements
- Inverters still not up to "Consumer" expectations
- Qualification Test Standard for inverters needed (Sandia)

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Interconnection

Observation: too many rules, no "commonalty"

- Protective Relays
- Manual Disconnects
- Islanding
- Reactive and Voltage Requirements

- Metering
- Legal Requirements
- Special Facilities Agreement
- Power Production Agreement

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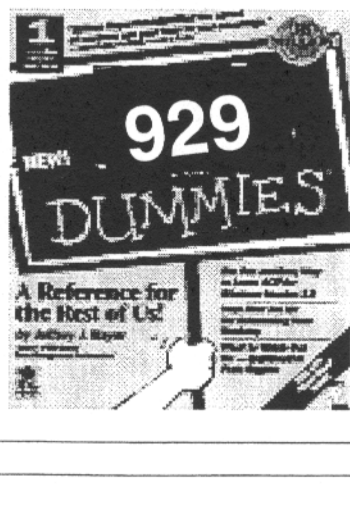
Observations

- Interconnection has not yet been a large issue, but still needs IEEE P929 established, accepted
- "929 for Dummies" type document planned by UPVG to convince non-technical audience that the IEEE 929 is worthy of acceptance



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Performance Index

- Dimensionless measure of performance: comparison of actual performance and a model output using site weather conditions
- PVUSA (and adopted by UPVG) Rating equation used:

$$Power = I*A + I^2*B + I*Tamb*C + I*W*D$$

Where:

I = Irradiance (W/m^2)
Tamb = Ambient Temp (C)
W = Wind Speed (m/s)

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Summary

- Continue "Safe" PV Installations
- Good "Systems" Engineering is Key
- Increased Reliability still a Goal

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Process Quality in Manufacturing PV Power Conversion Products

Dale R. Stefanac

OMNION Power Engineering Corporation

1998 Photovoltaic Performance and Reliability Workshop
Cocoa Beach, Florida
November 3 - 5

11/2/98

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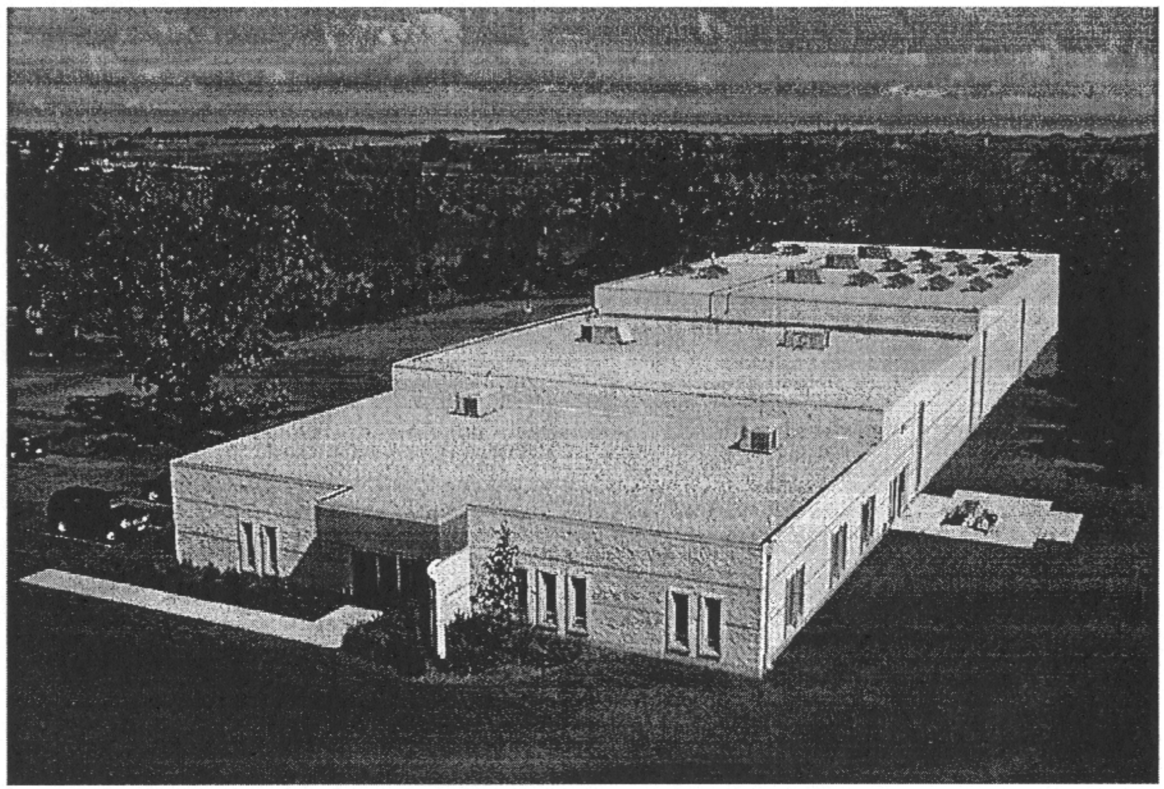

East Troy, Wisconsin

11/2/98

Discussion Topics

- What is ISO 9001 ?
- What does it mean to an organization ?
- What are the elements of ISO 9001 ?
- What is the ISO 9001 Registration Process ?
- Progress to date.
- Process/Product Improvements.

What is ISO 9001 ?

- ISO 9001 is an international Quality Standard (model) for an organization that is engaged in all aspects of design, manufacturing, and delivery of service.
- The 20 segments of the standard are considered to be the fundamental 'minimum' processes for doing business.
- Based on a third party assessment.

What does ISO 9001 mean to an organization ?

- Demonstrates a commitment to quality.
- Evidence of a company's internal discipline.
- Consistency and efficiency of work processes.
- Solid foundation for continuous improvement.
- Customer confidence.
- Automatic approval as a supplier.
- Marketplace recognition and compliance.

What are the elements of ISO 9001 ?

1. **Management Responsibility**

   Is management a major participant in the creation, monitoring, and improvement of the Quality System ?

2. **Quality System**

   Does the organization follow established, documented policies and procedures ?

3. **Contract Review**

   Are the needs and expectations of the customer met ?

4. **Design Control**

   Are new designs controlled and verified to assure that specified requirements are met ?

What are the elements of ISO 9001 ?

5. Control Document and Data

Are all documents relating to quality, reviewed, approved and is only the correct revision available ?

6. Purchasing

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Do procedures exist to insure that purchased products and services meet specified requirements ?

7. Control of Customer-Supplied Product

Are products supplied by customers adequately verified, stored and maintained ?

8. Product Identification and Traceability

Are products adequately identified through all stages of production, delivery and installation ?

What are the elements of ISO 9001 ?

9. Process Control

Are manufacturing processes and equipment monitored and controlled so that product specifications are met ?

10. Inspection and Testing

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Are manufacturing goods adequately inspected and tested at receiving during production, and after production ?

11. Control of Inspection, Measuring & Test Equipment

Is all equipment used to verify quality, controlled, calibrated and maintained ?

12. Inspection and Test Status

Is the inspection and test status of the product identified throughout production ?

What are the elements of ISO 9001 ?

13. Control of Nonconforming Product

Are procedures in place that prevent inadvertent use of non-conforming product ?

14. Corrective and Preventative Action

Are problems to be analyzed, corrective action taken and improvements made that prevent future recurrences ?

15. Handling, Packaging, Preservation and Delivery

Is adequate provision made for handling, packaging, preservation and delivery of products ?

16. Control of Quality Records

Are Quality records adequately identified, filed maintained and disposed ?

What are the elements of ISO 9001 ?

17. Internal Quality Audits

Are internal quality audits planned and documented to verify compliance to the quality system ?

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18. Training

Are training needs identified and training provided for all personnel performing activities related to quality ?

19. Servicing

Do procedures exist for performing and verifying contracted service ?

20. Statistical Techniques

Are statistical techniques adequate for verifying the acceptability of processes ?

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What is the Registration Process ?

Step 1: Review the ISO standard (elements).

Step 2: Determine organizational conformance to the standard.

Step 3: Establish an implementation team.

Step 4: Implement new quality system documentation.

Step 5: Find a regisitrar to conduct third party audits.

Step 6: Prepare for the third party assessment.

Step 7: Perform the assessment and evaluate results.

Step 8: Prepare for future assessments.

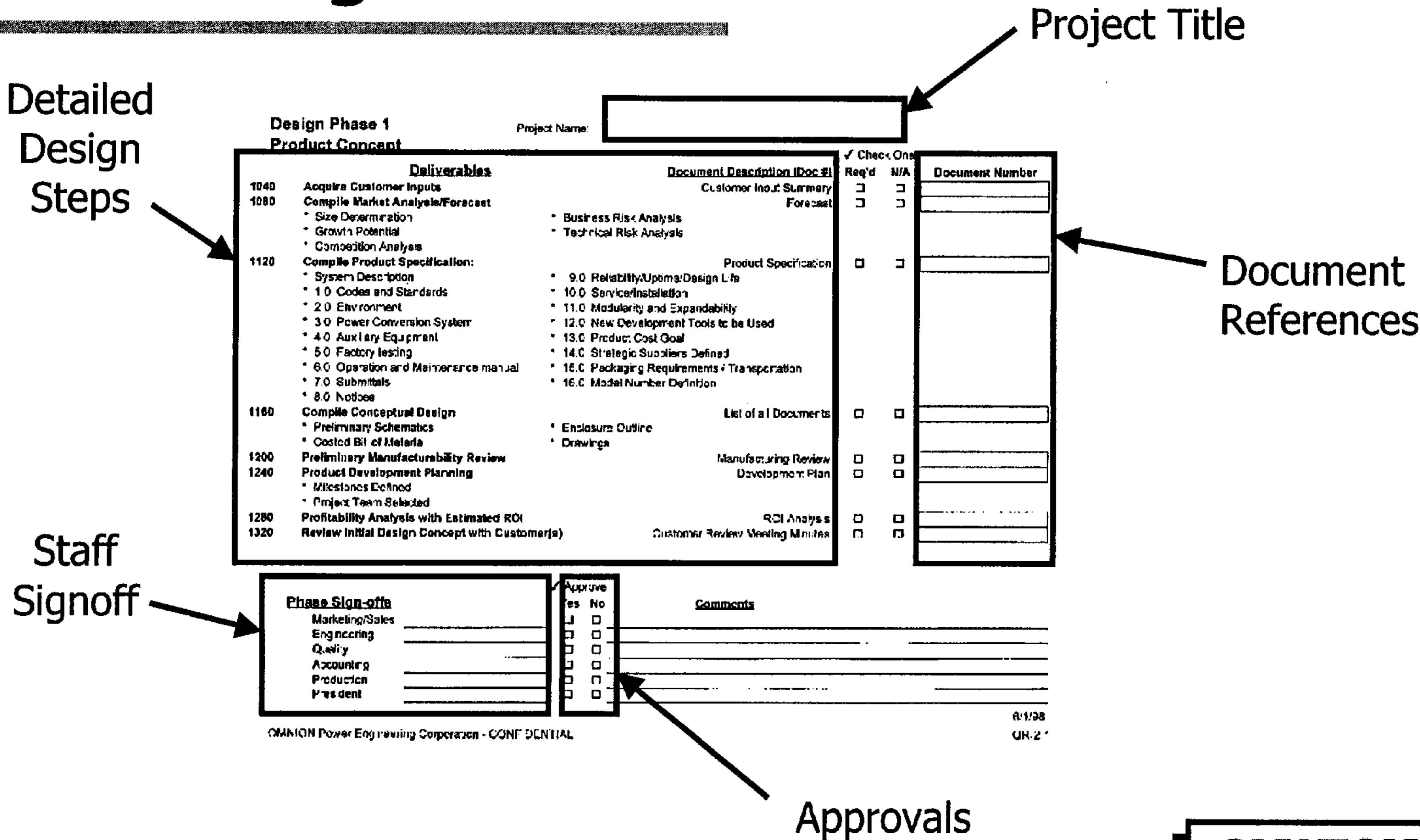
OMNION progress to date.

Step Description	Status
1) Review the ISO standard (elements).	COMPLETE
2) Determine organizational conformance to the standard.	COMPLETE
3) Establish an implementation team.	COMPLETE
4) Implement new quality system documentation.	40%
5) Find a regisitrar to conduct third party audits.	90%
6) Prepare for the third party assessment.	-
7) Perform the assessment and evaluate results.	-
8) Prepare for future assessments.	-

OMNION Process Improvements.

- Formal New Product Design Process
  1) **Product Concept**
  2) **Prototype Design, Build and Test**
  3) **Pilot Production**
  4) **Full Production**
  5) **End of Life**

Design Phase Checklists



Design Phase 1
Product Concept

Project Name:

	Deliverables		**Document Description (Doc #)**	✓ Check One Req'd	N/A	**Document Number**
1040	**Acquire Customer Inputs**		Customer Input Summary	☐	☐	
1080	**Compile Market Analysis/Forecast**		Forecast	☐	☐	
	• Size Determination	• Business Risk Analysis				
	• Growth Potential	• Technical Risk Analysis				
	• Competition Analysis					
1120	**Compile Product Specification:**		Product Specification	☐	☐	
	• System Description	• 9.0 Reliability/Uptime/Design Life				
	• 1.0 Codes and Standards	• 10.0 Service/Installation				
	• 2.0 Environment	• 11.0 Modularity and Expandability				
	• 3.0 Power Conversion System	• 12.0 New Development Tools to be Used				
	• 4.0 Auxiliary Equipment	• 13.0 Product Cost Goal				
	• 5.0 Factory testing	• 14.0 Strategic Suppliers Defined				
	• 6.0 Operation and Maintenance manual	• 15.0 Packaging Requirements / Transportation				
	• 7.0 Submittals	• 16.0 Model Number Definition				
	• 8.0 Notices					
1160	**Compile Conceptual Design**		List of all Documents	☐	☐	
	• Preliminary Schematics	• Enclosure Outline				
	• Costed Bill of Materials	• Drawings				
1200	**Preliminary Manufacturability Review**		Manufacturing Review	☐	☐	
1240	**Product Development Planning**		Development Plan	☐	☐	
	• Milestones Defined					
	• Project Team Selected					
1280	**Profitability Analysis with Estimated ROI**		ROI Analysis	☐	☐	
1320	**Review Initial Design Concept with Customer(s)**		Customer Review Meeting Minutes	☐	☐	

Phase Sign-offs		✓ Approve Yes	No	**Comments**
Marketing/Sales		☐	☐	
Engineering		☐	☐	
Quality		☐	☐	
Accounting		☐	☐	
Production		☐	☐	
President		☐	☐	

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Series 2400 Inverter Product Improvements

- Cooling System
  - Biological corrosion prevention (July, 1997)

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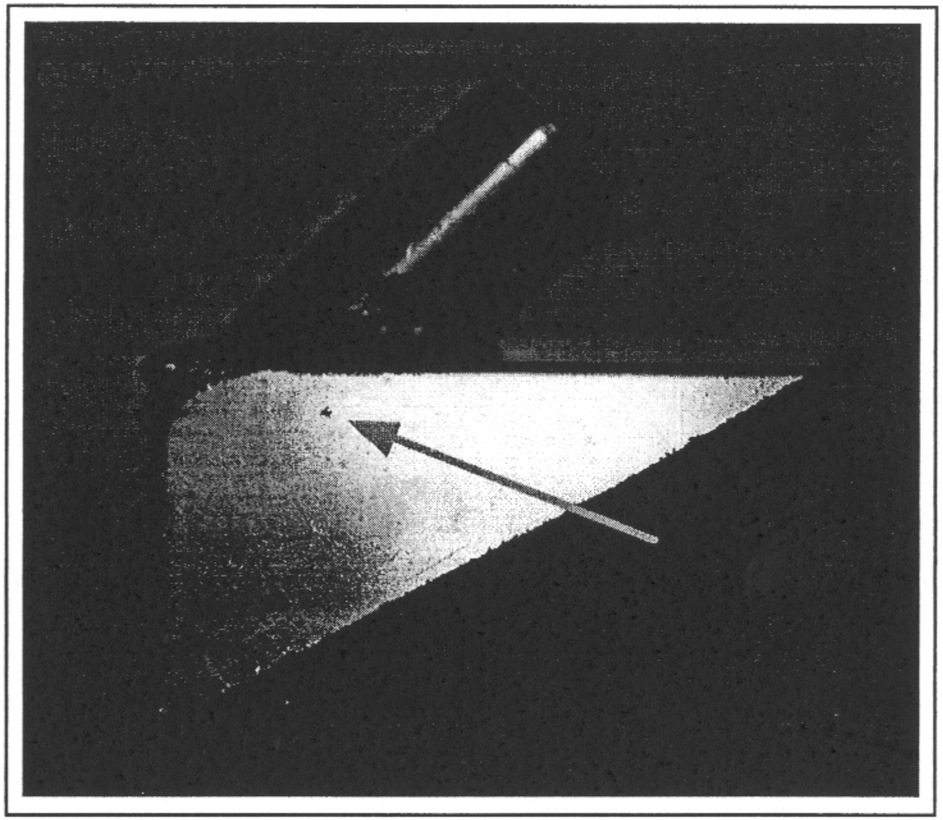
Series 2400 Inverter IGBT coolant tank



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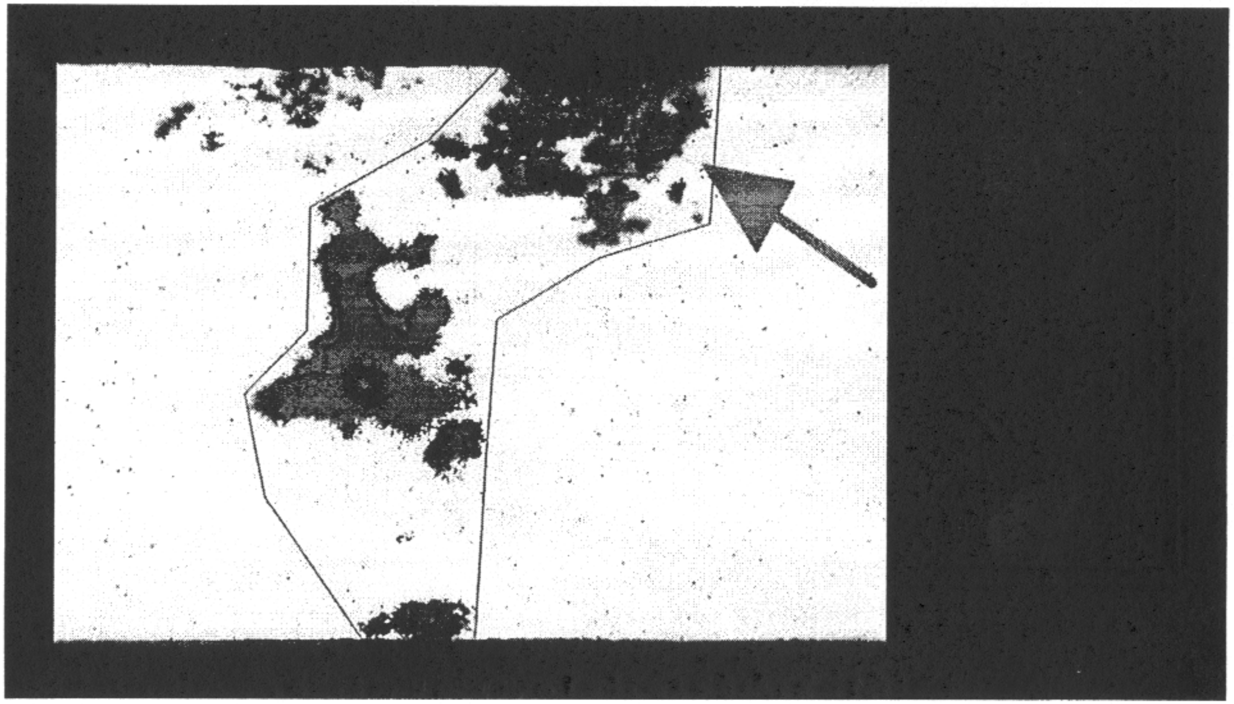
Series 2400 Inverter
IGBT coolant tank wall section



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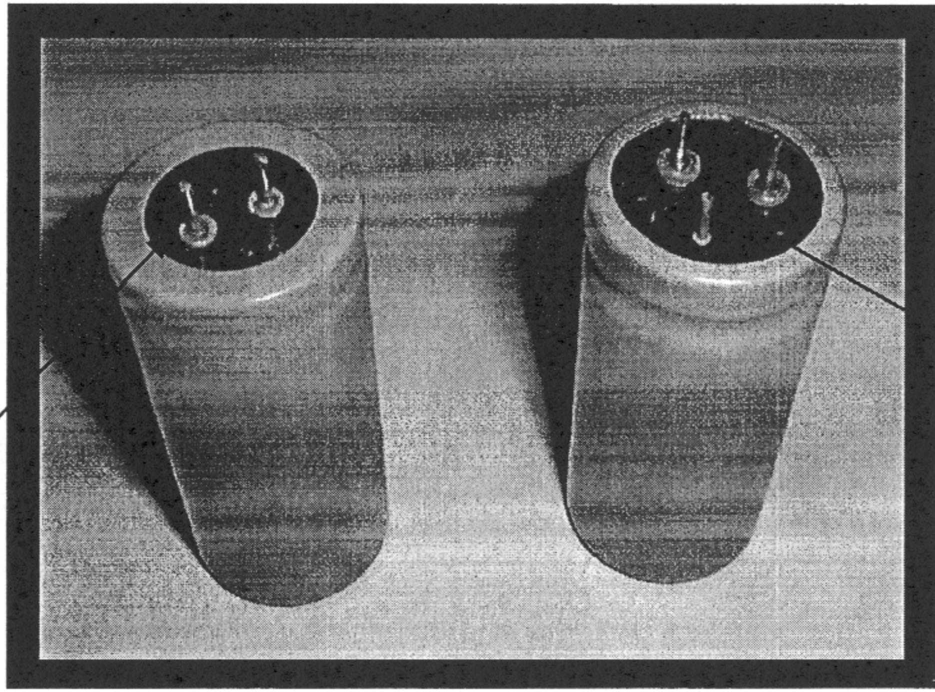
Series 2400 Inverter Product Improvements

- Cooling System
  - Biological corrosion prevention (July, 1997)
- Electronic Assembly
  - Elimination of capacitor breakage (November, 1996)

Series 2400 Inverter
2 and 3 pin capacitors



2 pin

3 pin

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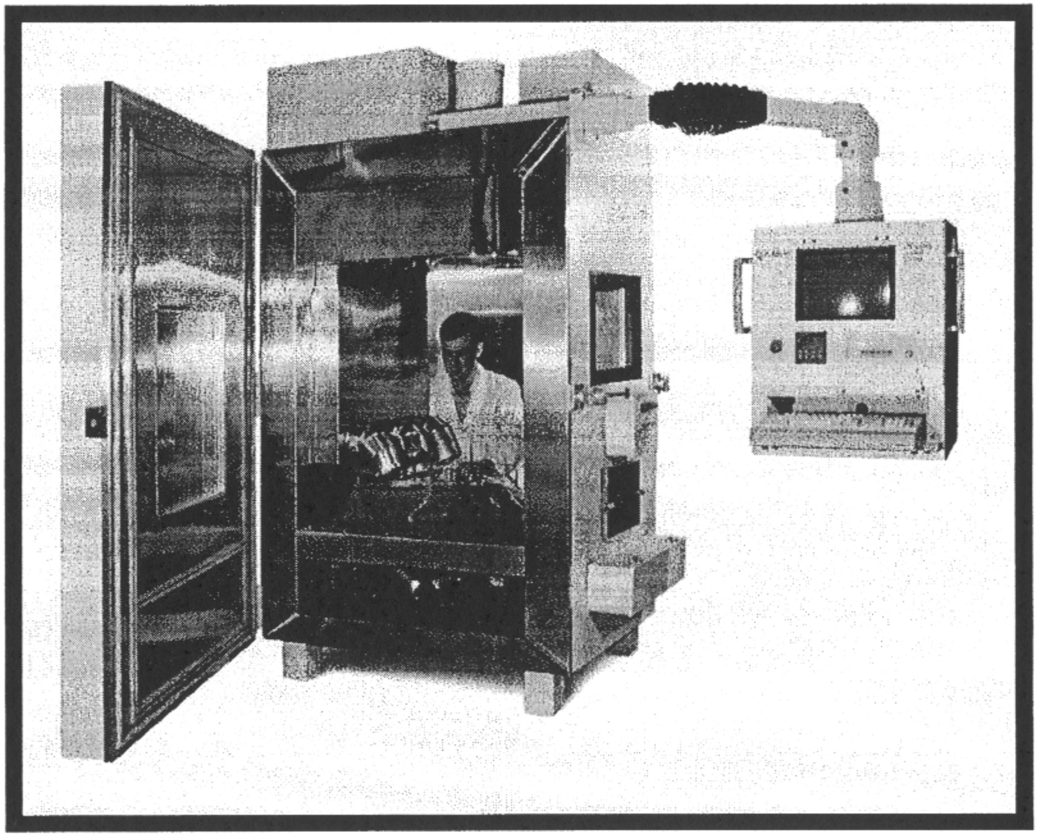
HALT Product Testing

(Highly Accelerated Life Test)

QualMark
OVS-2.5 HP
Thermal
Chamber



Test space
36"w 36"d 37" h

QualMark Corporation
New Brighton, MN

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Highly Accelerated Life Testing (HALT)
Series 2400 Inverter
Tested September 16-19, 1997

- Thermal Step Stress: +/- 10 C steps every 12 minutes (from 20 C)

  Results: Inverter operated correctly between - 40 C and 80 C ambient. (LCD was not readable below -20 C and above 80 C)
- Rapid Thermal Stress: -50 C to 120 C @ 10 C/minute

  Results: Inverter operated correctly between - 40 C and 120 C ambient. (LCD not readable below -20 C and above 80 C)
- Vibration Stress: 5 to 45 G; 5 G steps every 12 minutes

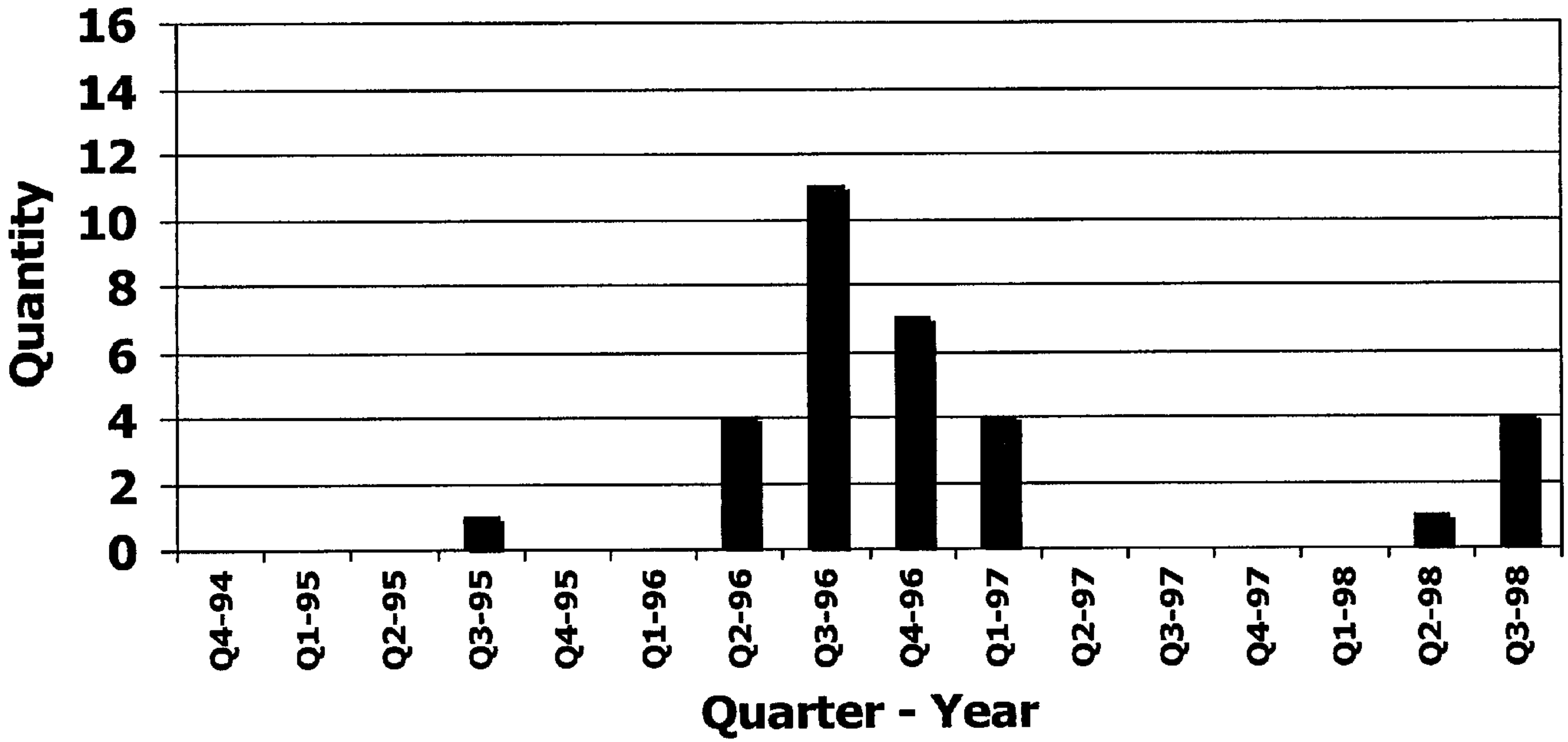
  Results: Inverter operated correctly between 5 and 40 G.
- Combined:Thermal Step and Vibration: 5 to 45 G; 5 G steps every 12 minutes (at 20 C)

  Results: Similar to combined results shown above.

Series 2400 Inverter Product Improvements

- Cooling System
  - Biological corrosion prevention (July, 1997)
- Electronic Assembly
  - Elimination of capacitor breakage (November, 1996)
- Software
  - Elimination of inverter shutdown (March, 1997)
  - Reduction in "DC INJECTION" shutdowns (October, 1997)
- Packaging
  - Strengthening of shipping package (September, 1997)

1994 Series 2400 Inverter Repairs



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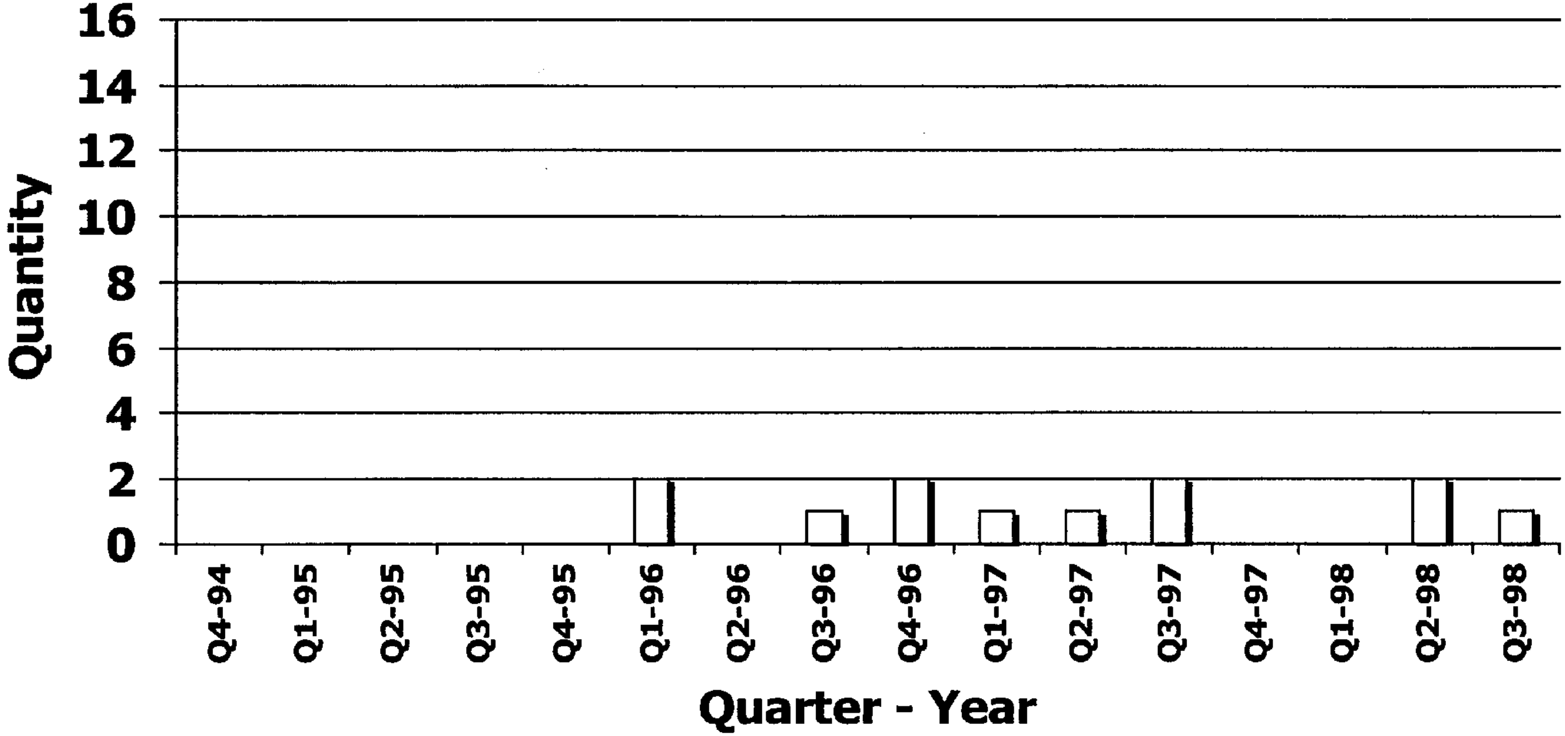
1995 Series 2400 Inverter Repairs



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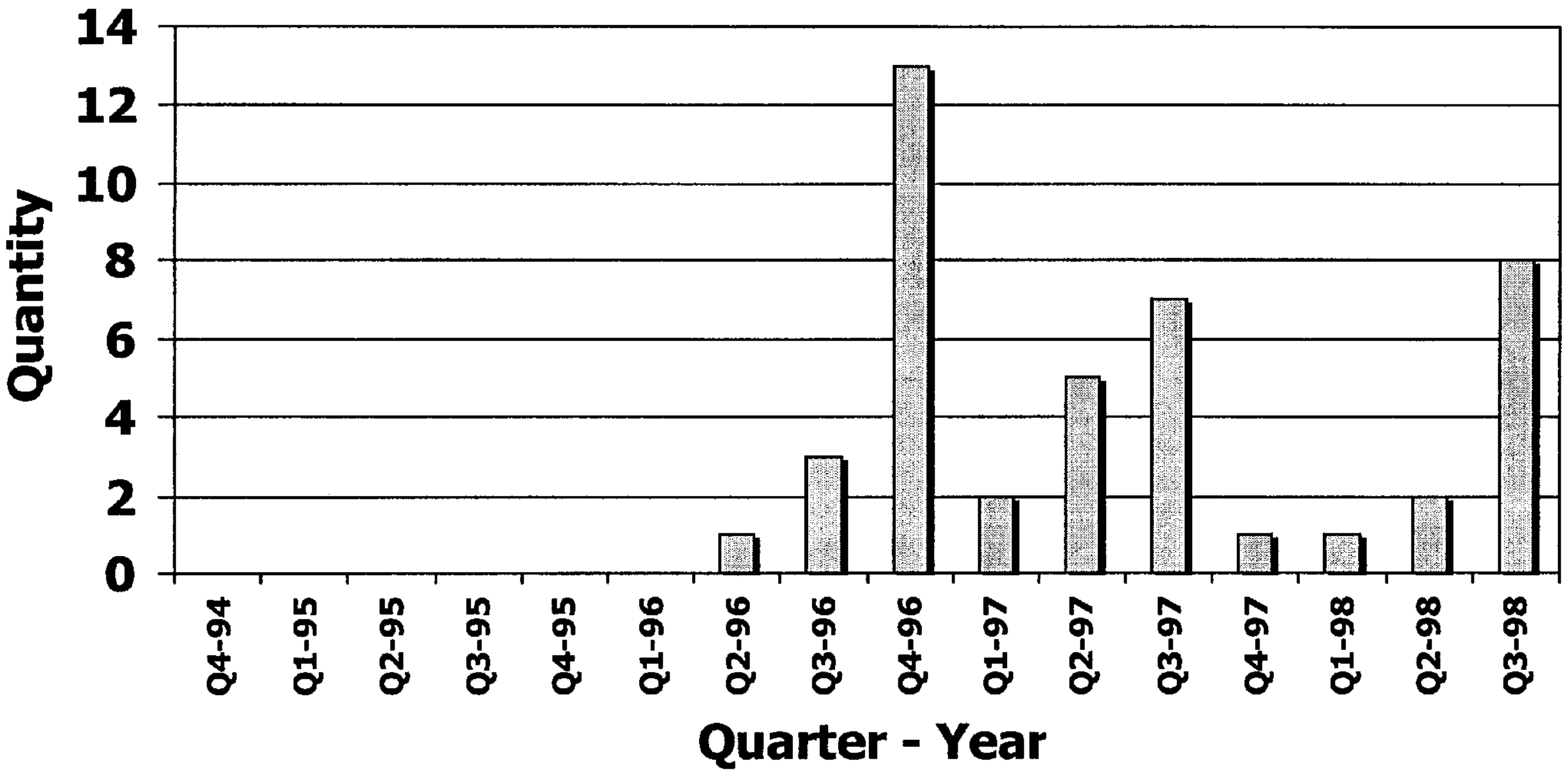
1996 Series 2400 Inverter Repairs



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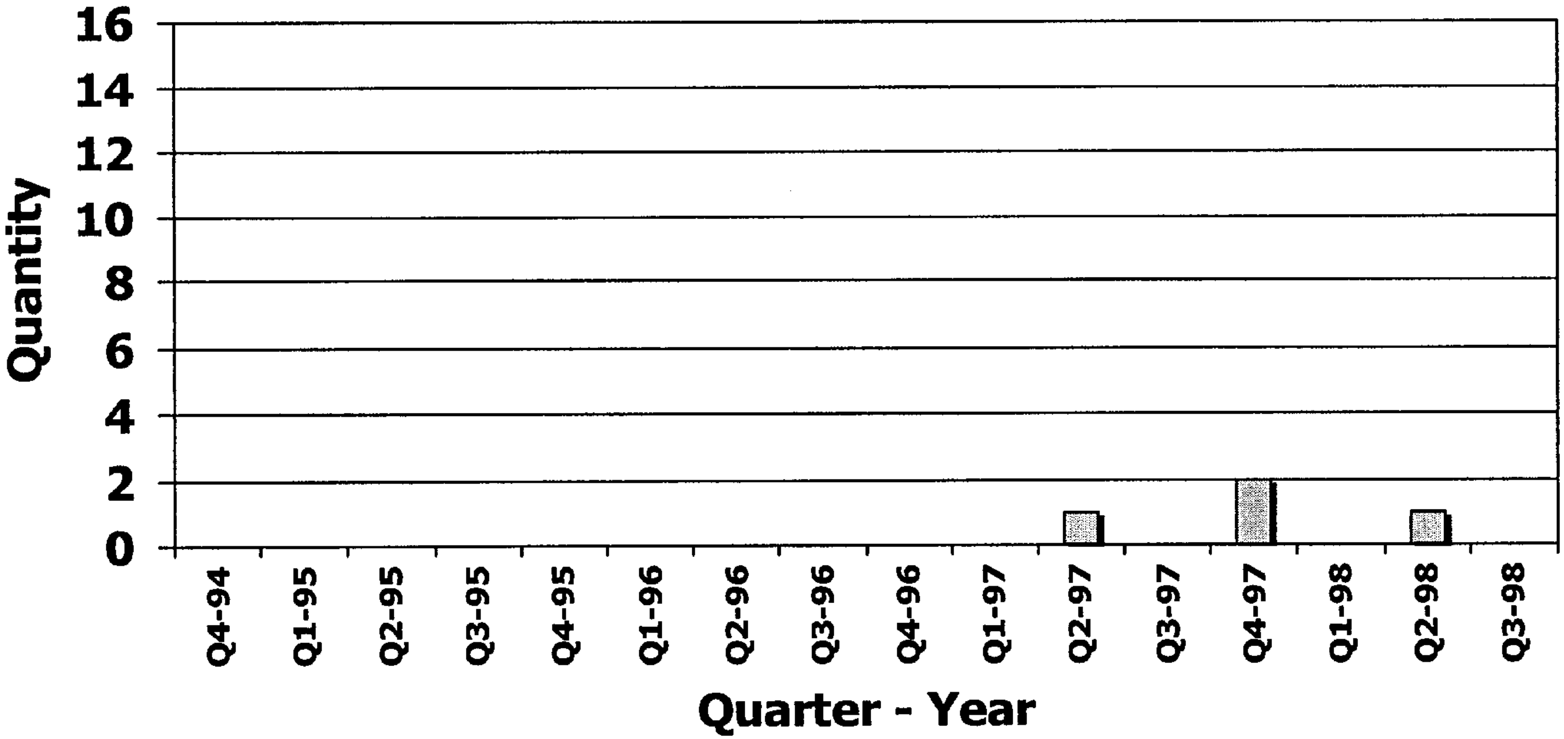
1997 Series 2400 Inverter Repairs



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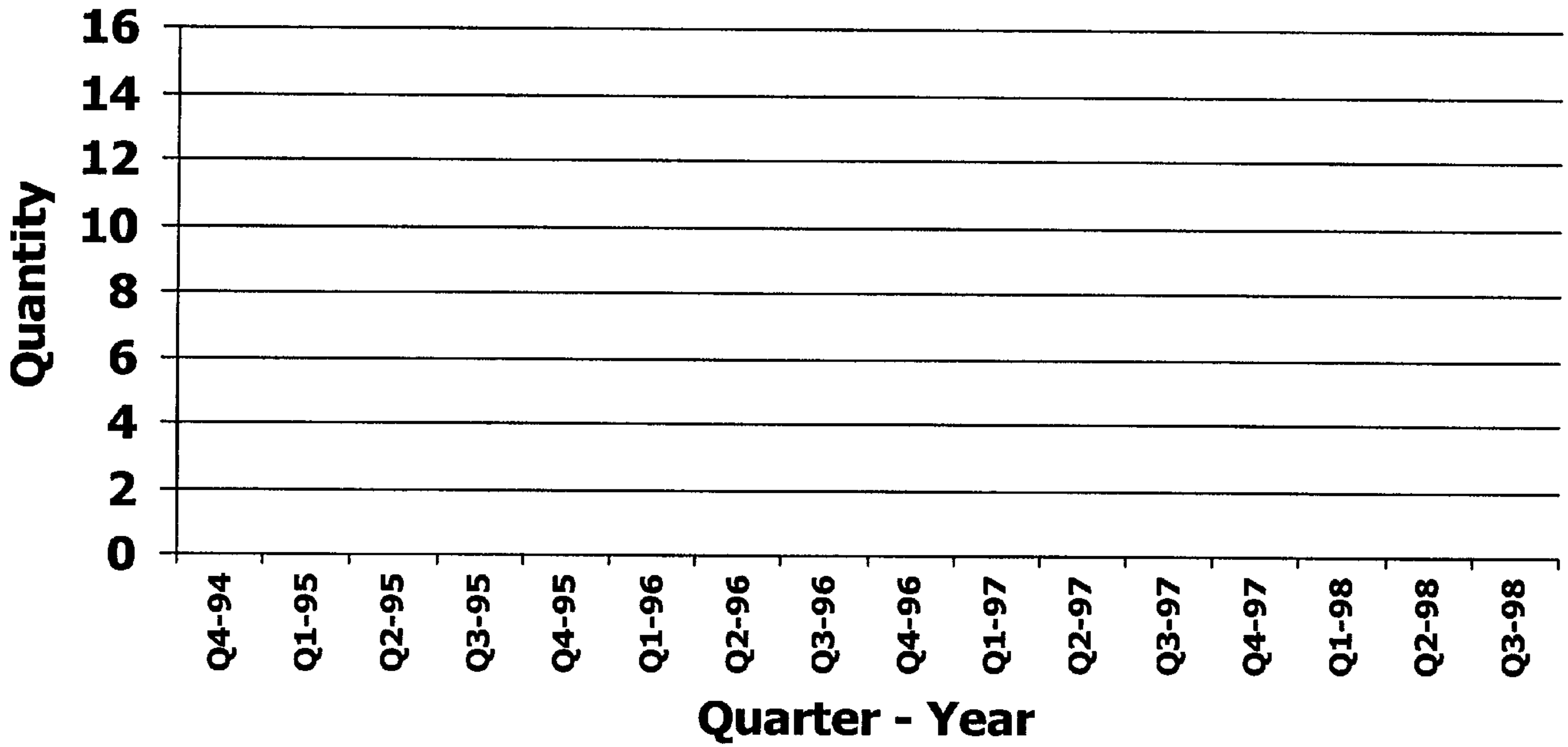
1998 Series 2400 Inverter Repairs



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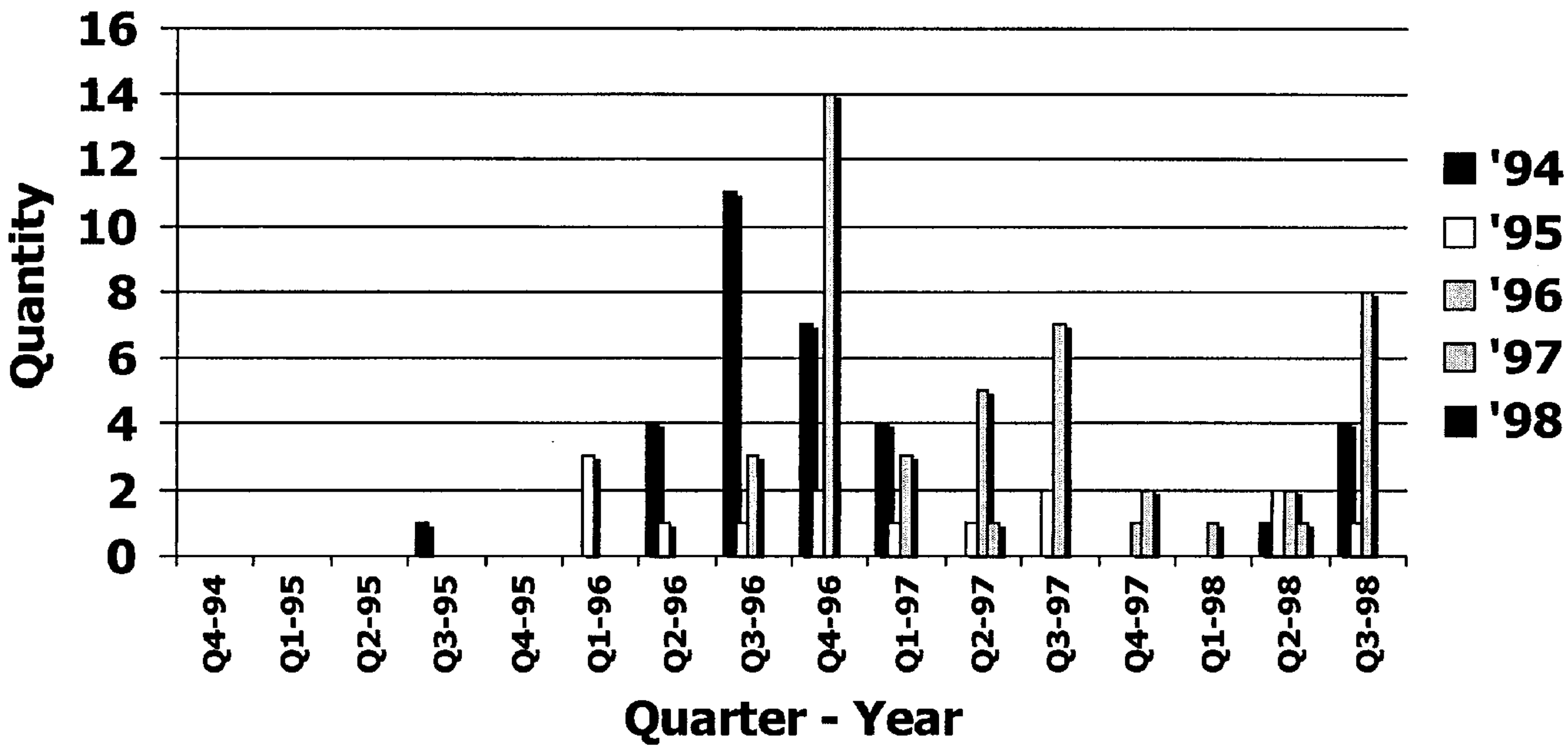
Series 2400 Inverter Repairs Q4/1994 through Q3/1998



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Summary

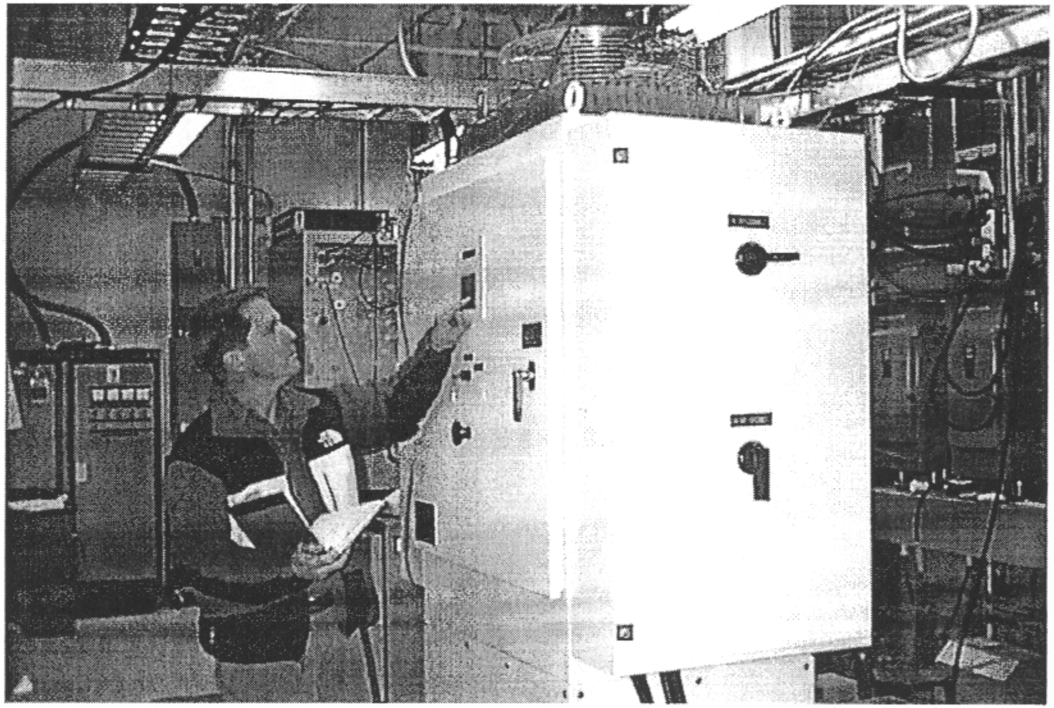
- OMNION is committed to provide PV Power Conversion products of the highest quality and reliability.

- We base our commitment on an organization-wide belief that quality begins with excellence in design and manufacturing processes.

- Our dedication to the implementation of an ISO 9001 Certified Quality System has set the foundation for a leadership position as an inverter supplier.

Testing and Development of a 30-kW Hybrid Inverter Lessons Learned and Reliability Implications

Jerry Ginn 505-845-9117, jwginn@Sandia.gov



30-kW Trace Technologies Hybrid Inverter
PSEL-WEST (SNL Inverter Test Lab)

Content of talk

- Why hybrids?
- Background of project
- Specifics
  - Description
  - Enhancements
  - Lessons learned

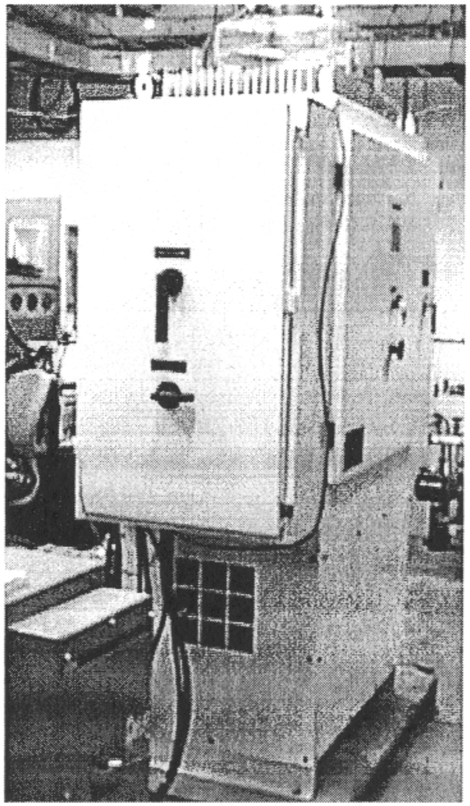
Why hybrid systems?

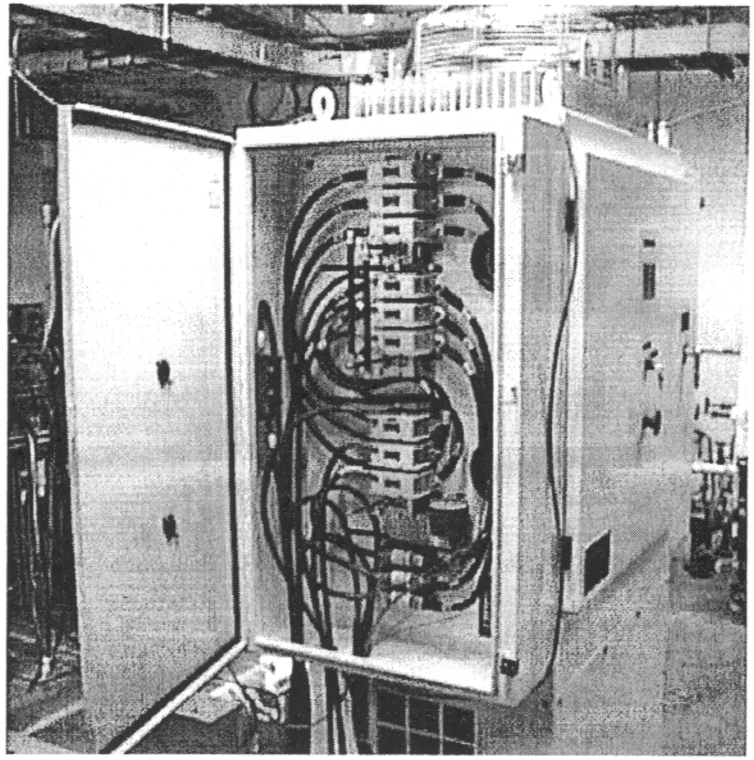
- Remote engine-generator-only power system issues
  - reliability
  - fuel cost/delivery
  - maintenance
- Add batteries and PCS to improve engine performance in variable load applications
  - **fully load diesel generator**
  - **reduce engine run time**
  - **add redundancy**
- Add PV (or other charging source)
  - **further reduce engine run time**
- Economics are site-specific:
  - **consult Rick Chapman (505) 844-0859**

Background of project

- Support Arizona Public Service
  - STAR hybrid test facility
- Support Sandia Energy Storage System department
  - Yuasa tubular gel batteries at STAR
- Address observed problems:
  - Reliability issues
  - Application-specific designs
- Decision to use Trace Technologies
  - Santa Cruz (USN) procurement in place
  - specs modified for more generic design
  - same power electronics
  - rugged design
  - 2 of 2 vs. 1 of 1

Description





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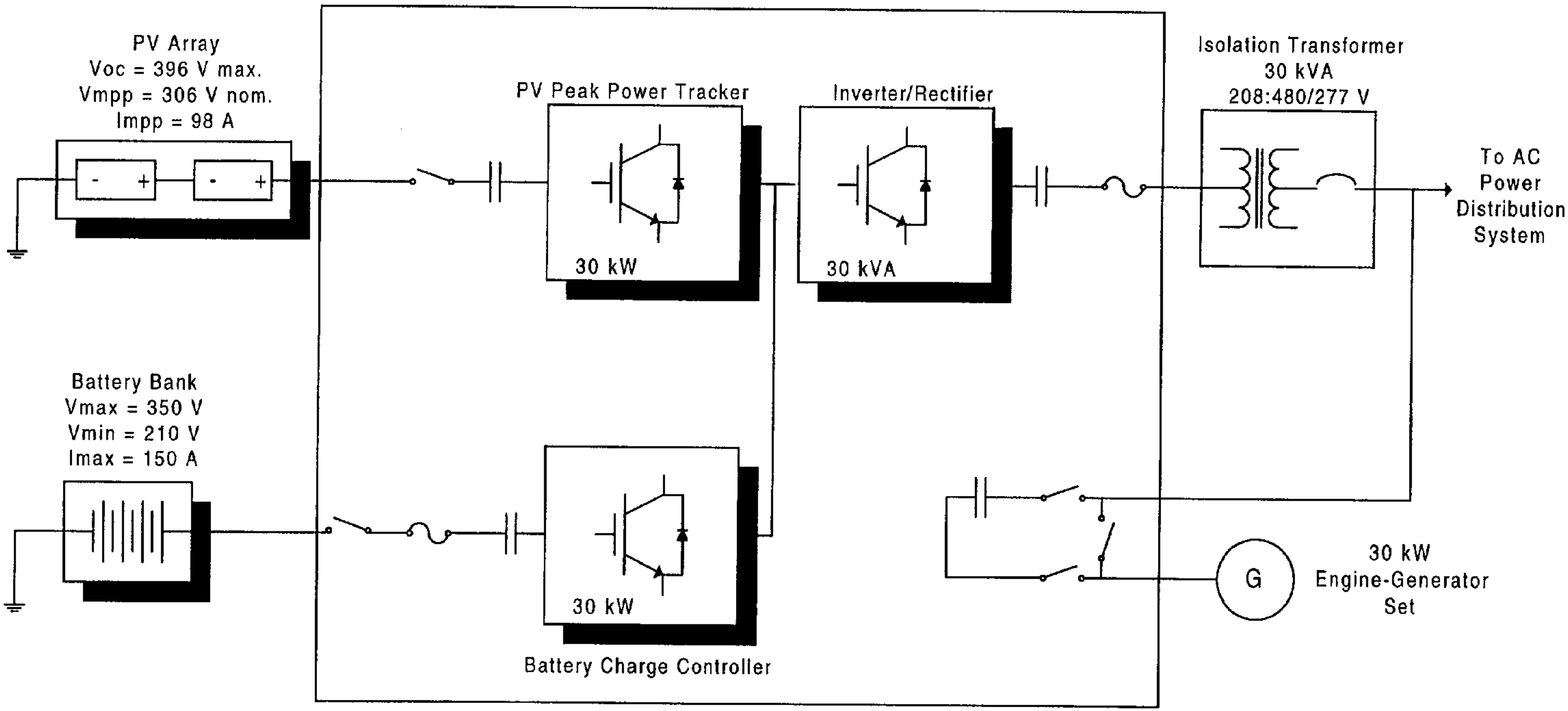
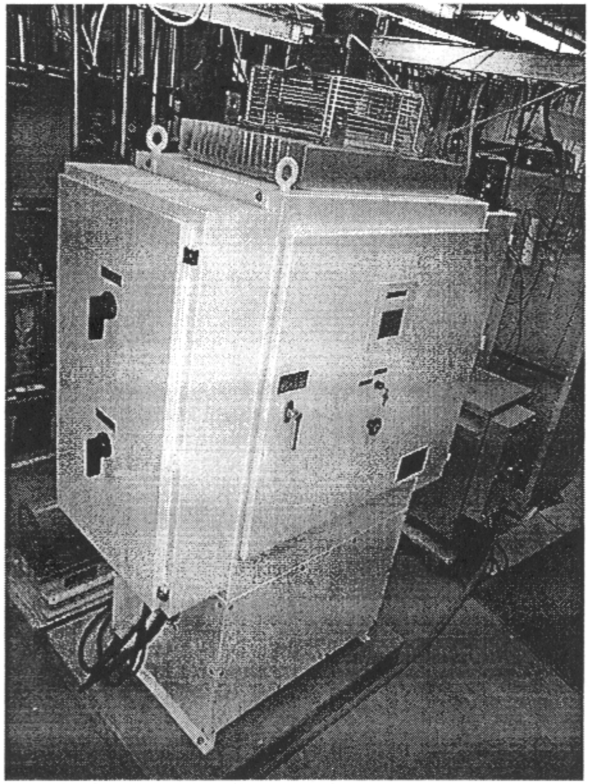
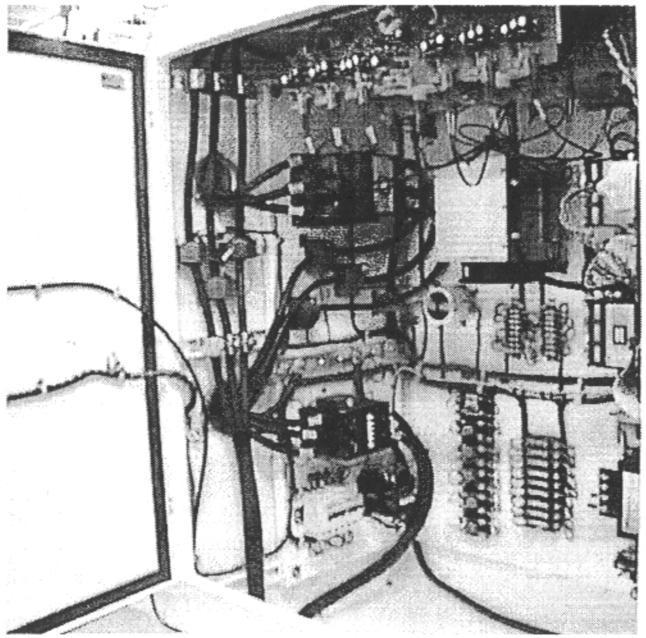
Single-line diagram



Enhancements





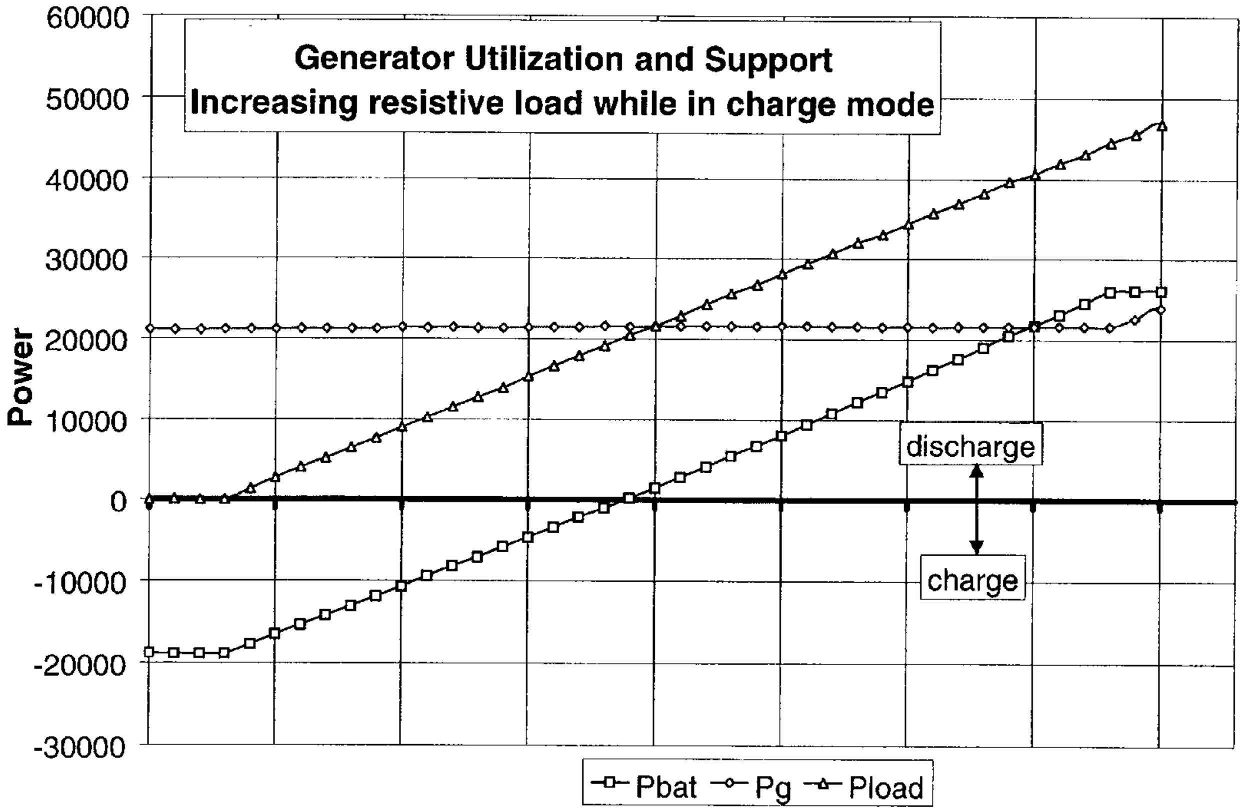
National Center for Photovoltaics

Sandia National Laboratories

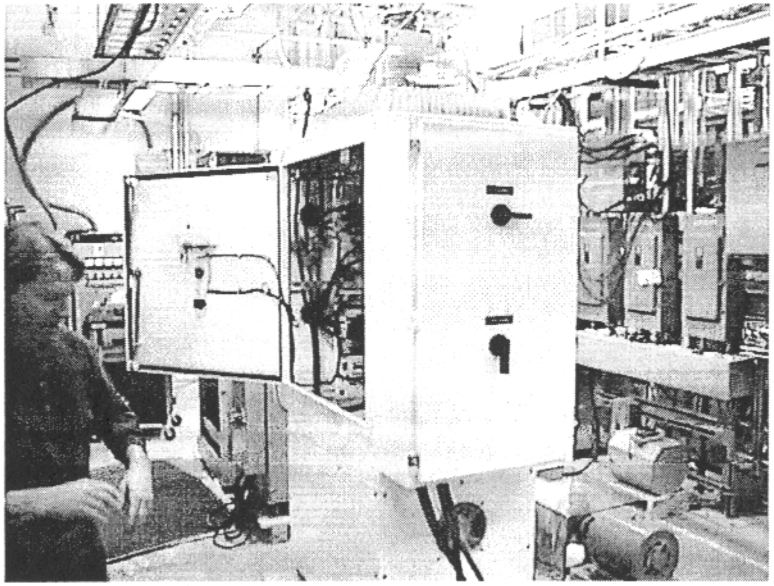
Developmental changes resulting from SNL/APS evaluation

	Problem	Modification
1	Terminology confusing	"Generator Only" replaces "Shutdown"
2	Blackout if generator fails to start	INV mode continues to V_BDOD "Generator Fault" contacts added
3	10-hp motor start causes overload trip	Overload capability increased in controls
4	No parallel capability during overloads in INV mode	Capability added
5	Charge loads generator too rapidly	Slowed to 8-sec ramp
6	Automatic restart of inverter following generator fault	Capability added
7	Marginal Generator creates problems with support, utilization, and overloads	Front-panel selection of generator size added
8	Inverter output capacitors reduce useful charging capacity from generator	Reactive power now provided from inverter More generator power available for charging
9	PV not operating at max power point	Current and time step controls added Good agreement with curve tracer
10	PV power feeding back into generator	Reverse-power protection added
11	Charge may terminate prematurely due to large loads	Additional test forces complete charge
12	Equalization may be inadequate due to large loads	Additional test forces complete equalization time
13	No provision for generator "quiet time"	Quiet time added
14	Sunlight changes cause step load changes to generator	MPT step size softens power increases
15	No direct battery temperature input	Temperature input added to controls Transducer and power supply provided "Battery temperature out of range" fault condition added
16	Documentation of user settings and factory defaults	Provided

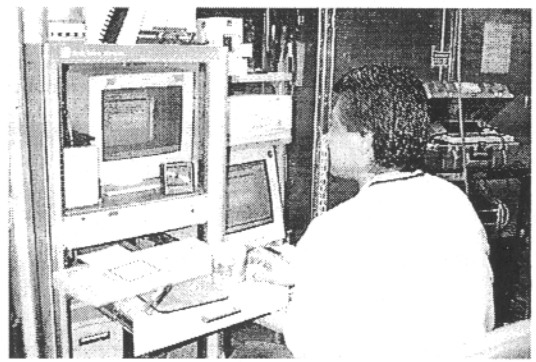
Inverter fully loads and supports generator



Lessons learned



- Battery management
- Generator selection
- Site load management

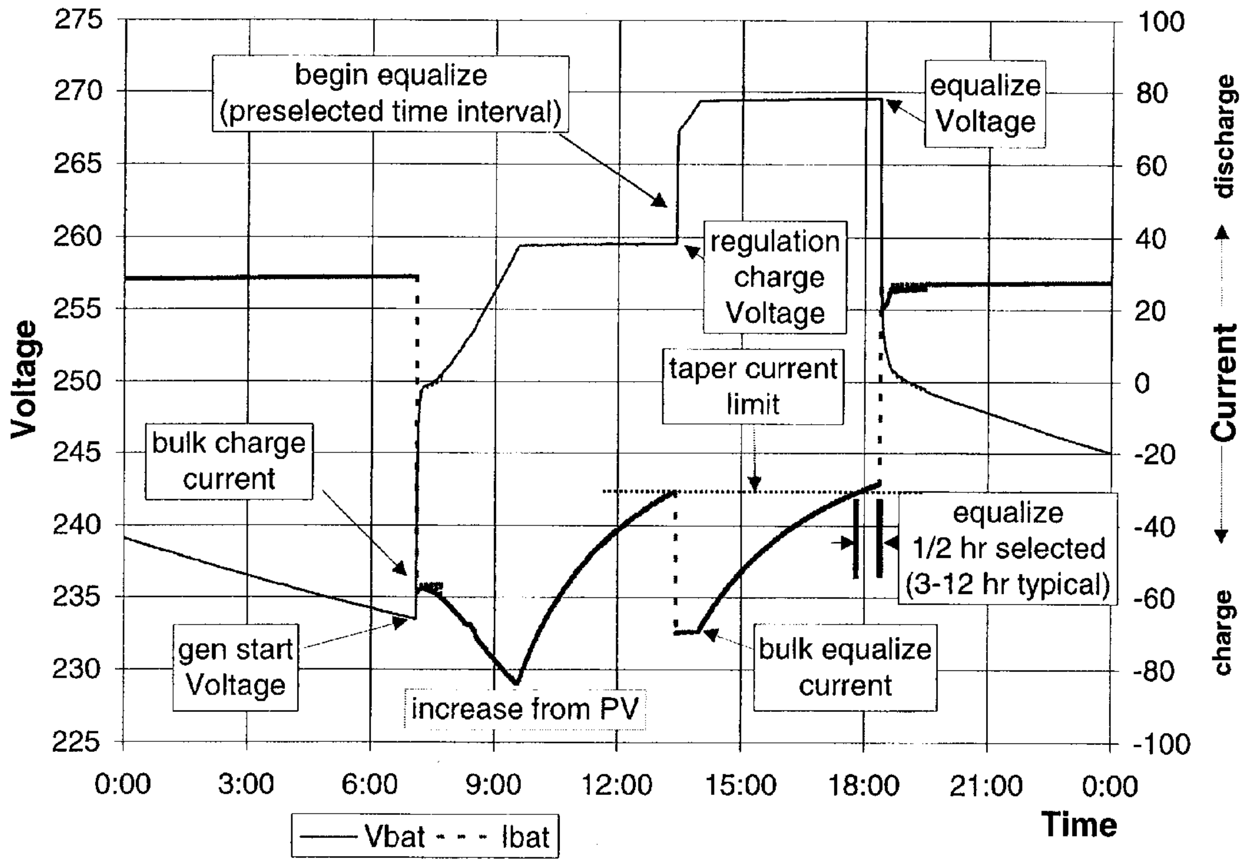


Improper charging affects battery performance

- ***System life-cycle cost depends heavily on battery lifetime***
- All PV applications are **cycling**; charge requirements differ from **float**
  - higher charge voltage (flooded & valve-regulated)
  - longer duration finish charge for valve-regulated
- Normally state-of-charge only estimated, so cycle-to-cycle:
  - *charge deficit builds*
  - *capacity can be reduced*
- Batteries require ***complete finish charge*** to minimize capacity loss
- Economic penalty: extended diesel run time

(Note: "Finish charge" and "equalization" often used interchangeably but true equalization begins when finish charge ends)

Original battery charge algorithm (vented battery)



Note: values (v, i, t) for illustration only!!

Flooded (vented) lead-acid battery suggested setpoints to obtain rated battery cycle life

Variable	Minimum Lead-Antimony	Maximum/Equalize Lead-Antimony
PV Regulation Voltage (Vr) @ 25°C	14.4/2.40 vpc Constant Voltage 14.7-13.5/2.45-2.28 vpc On-Off	15.3/2.55 vpc Constant Voltage 15.3-13.7/2.55-2.28 vpc On-Off
Engine Generator Vr @ 25°C	14.4/2.40 vpc to 15.3/2.55 vpc	15.3/2.55 vpc
Engine Generator Time @ Vr	0 to 3 hr. (Bulk Charge, 3-day max interval)	5 to 12 hr. (15-day max interval)
Engine Start Voltage	11.7/ 1.95 vpc (12.0/2.0 typical)	
Low Voltage Disconnect (LVD)	11.4/ 1.9 vpc	
Temperature Coefficient V/°C/cell	-0.005	

Follow battery manufacturer's recommendations!

VRLA (sealed) lead-acid battery suggested setpoints to obtain rated battery cycle life

Variable	Minimum VRLA	Maximum/Equalize VRLA
PV Regulation Voltage (Vr) @ 25°C (Constant Voltage Charging)	14.1/2.35 vpc or 14.4/2.40 vpc	14.1/2.35 vpc or 14.4/2.40 vpc
Engine Generator Vr @ 25°C (Constant Voltage Charging)	14.1/2.35 vpc or 14.4/2.40 vpc	14.1/2.35 vpc or 14.4/2.40 vpc
Engine Generator Time @ Vr	0 to 6 hr. (Assumes engine-gen finish chg)	12 hr. (7-15-day max interval dep on system design)
Engine Start Voltage	11.7/1.95 vpc (12.0/2.0 vpc typical)	
Low Voltage Disconnect (LVD)	11.5/ 1.92 vpc	
Temperature Coefficient V/°C/cell	-0.005	

Follow battery manufacturer's recommendations!

Proper Battery Charging of PV Hybrids

- Any PV hybrid battery management strategy should limit the number of days the battery spends in a deficit charge condition and provide a means for full recovery ("equalization") of that battery on a regular basis.
  - Tom Hund

Generator selection

•Steady-state

Two choices to minimize droop in generator frequency :

1. Oversize generator (poor choice)

   increases operating cost

2. Use isochronous governor (better choice)

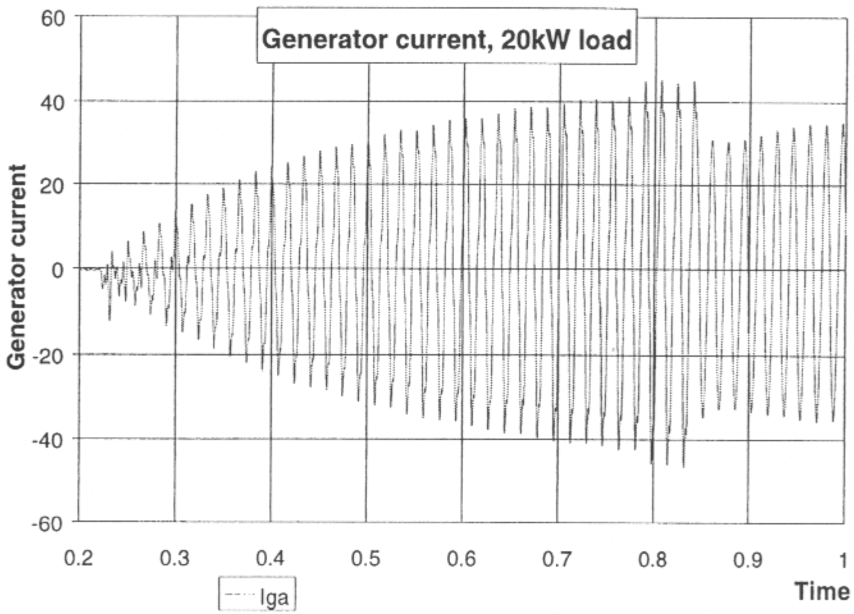
•Transient

Response affected by many factors:

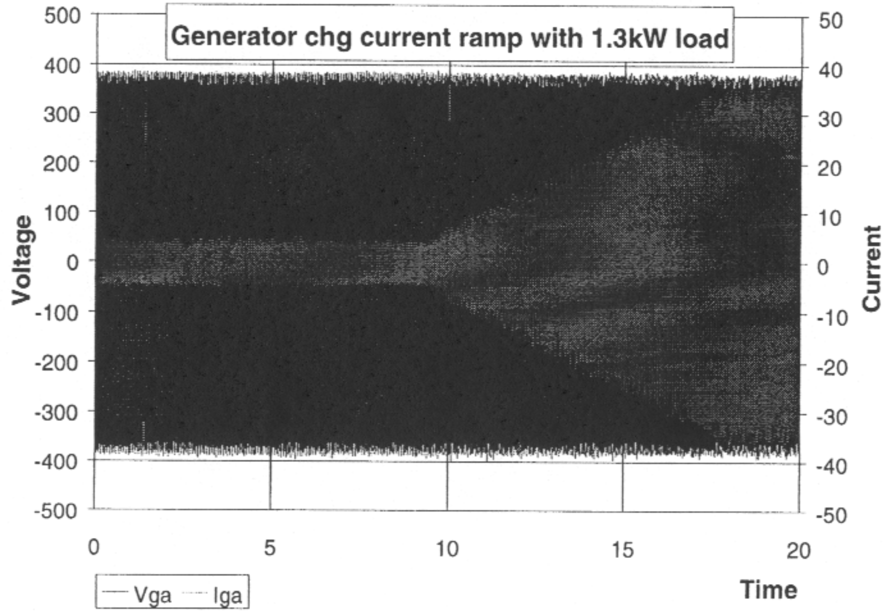
specify block load capability if needed

Inverter applies load to generator gradually

Inverter to generator



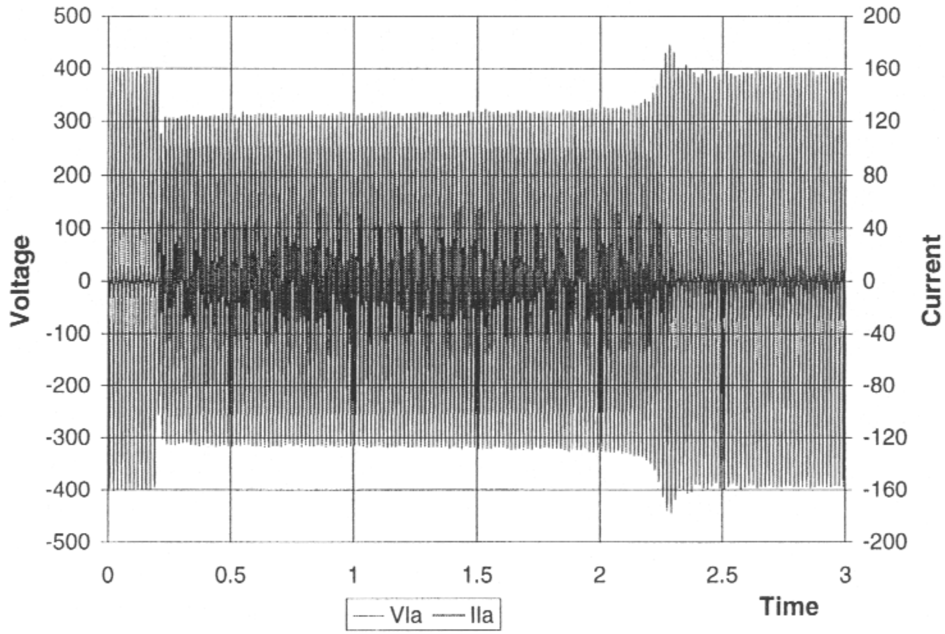
Charge Current Ramp



Load management is integral to system design

inverter ≠ U.S. power grid

10-hp motor start with 6.4-kW parallel load



Significant voltage sags possible when starting motors

- consider reduced-voltage or soft starters
- avoid simultaneously starting multiple motors

Hybrid systems performance and reliability are affected by:

- Battery management
  - temperature compensation needed
  - don't let batteries rest at low state of charge
  - complete finish charge ("equalize") often
    (helps recover from inadequate normal charging)
- Generator selection
  - isochronous governor allows smaller generator
  - advanced inverter controls may "fix" poor generator but add complexity
- Site load management
  - Reduced voltage or soft starters for "large" motors to minimize sag
  - UPS for sensitive electronic loads

Inverter Status

- Extended development test time led to many improvements
- Rugged ***(No Shrapnel)***
- More flexible design
- 30-kVA unit presently powering APS STAR hybrid test facility

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National Center for Photovoltaics

Defining Requirements for Improved PV System Reliability

Alex Maish
Sandia National Laboratories

Overview

- Present a Framework for understanding system reliability and its impact on achieving Sustainable PV systems.
- Provide an review of reliability issues and needs by PV application sector.

Sandia National Laboratories

National Center for Photovoltaics

What is System Reliability?

- A reliable PV system meets its functional requirements (operates as expected), i.e. lighting, pumping, power to the grid. Thus, the system includes the load.
- System reliability is distinct from component reliability:
  - Components can fail and the system can continue to operate. Ex: dual lights.
  - Components can operate and the system can fail. Ex: poor quality light.

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What are the Metrics of System Reliability?

- Intermediate metrics: mean time between failure (MTBF), mean time to repair (MTTR), availability.
- Ultimate metric is cost which contributes to levelized cost including:
  - Operation and Maintenance (O&M) cost.
  - Capital and Capital Replacement cost spent to avoid O&M costs. Ex: Gel batteries, dual lights.
  - Lost value cost from downtime. Ex: Lost power to grid, lost value of load (lights, livestock, communication, etc.)

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What is required to achieve Sustainable PV Systems?

$$LC = [Capital] + Cap\ Repl + O\&M \leq Value$$

- Sustainability requires system levelized cost be less than value of achieving system functional requirements.
- Ongoing Costs require ongoing Value to the payer.
- If Capital Cost is not a levelized expense, it may not be part of the sustainability equation.

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Optimization Requires Consideration of all Components Together

- Components must be optimized as a system, not independently. Ex: Battery charging in a hybrid system.
- Value depends on efficient operation of all system components. Ex: Low efficiency ballast or lights.
- Low performance and degradation impact value but not reliability until they prevent achieving the functional requirements and/or warrants maintenance or capital replacement costs.

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Value determines allowable system O&M expenses

- A low criticality (value) system may be left unserviced until it is economical to do so, such as the next scheduled maintenance. Ex: Grid-tied systems, area lighting.
- A high criticality system may warrant preemptive scheduled maintenance or a remote data acquisition system (DAS) to anticipate maintenance. Ex: remote telecommunication system.

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What are the Core Elements to achieving Reliable PV Systems?

1) System design must be appropriate for the resource, load, local servicing infrastructure, and the user.
   - Understand component operation and interaction.
   - Select appropriate components - Maintenance often governs the design, especially in battery storage systems.
   - Appropriate sizing of components.
   - User-friendly design for error-free installation and servicing.
   - Design must match the skills of the installer/servicer.
2) Component reliability must be adequate relative to value.
3) Quality installation & maintenance. Presently requires a trained technician.

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Current Issues in PV System Reliability

- Grid-Tied Residential & Commercial
- Grid-Tied Bulk-Power
- Remote, non-Hybrid
  - Direct Power (water pump)
  - Battery Storage (lighting, telecommunication, cathodic protection)
- Remote Hybrid

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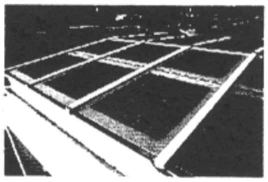
Grid-Tied Residential and Commercial Applications

- **Functional Requirements:** Provide Energy to the grid (at a specified performance level?)
- **Value of System:**
  - Value can include externalities (green pricing).
  - Energy value is low, 3-10¢/kWh.
  - O&M cost target: <1¢/kWh?
  - Individual system is mid-sized: 2-100kW.
  - Per system energy value is 30¢ to $50/day.
  - Per system allowable O&M is $37 to $1825 per year.
  - 2kW system with $500 out-of-warranty inverter repair requires 14 year MTBF.



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Grid-Tied Residential and Commercial Applications - What are the Issues?

- Scarce O&M data: SMUD, Ascension.
- **System design** - Well understood. Not an issue if executed well, i.e. comply with NEC, minimize assembly, standardize systems to improve servicing and resolve design issues.
- **Component reliability** - Has been an issue, esp. inverters. Progress is being made. MTBF has about doubled recently.
  - SMUD-incurred costs are ~1¢/kWh and dropping.
  - Out-of-warranty repair costs are 2-3X higher.
- **Installation/Maintenance** - Distributed generation requires distributed installation/maintenance. Strategies to reduce cost: Standard designs, aggregate service calls, in-truck inventory, extended component warranties.

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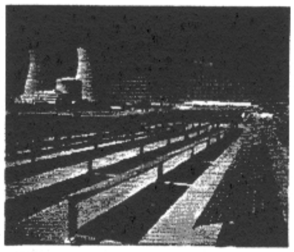
Grid-Tied Bulk Power Applications

- **Functional Requirements:** Provide Energy to the grid (at a specified performance level?)
- **Value of System:**
  - Energy value is low, 3-5¢/kWh.
  - O&M cost target: <0.1¢/kWh?
  - Individual system is large: 100kW-5MW.
  - Per system value is $15 to $1250/day.
  - Per system allowable O&M is $182 to $9125 per year.
  - 200kW system with $1000 repair requires 2.7 year MTBF.



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Grid-Tied Bulk-Power Applications - What are the Issues?

- Scarce O&M data: PVUSA, SMUD's PV1, PV2, Hedge
- **System design** - Well understood. One-axis tracking flat plate systems predominate.
- **Component reliability** - Issues with inverters, transformers.
  - Electromechanical trackers can be very reliable:
    - PV1, PV2 tracker MTBF is few failures per 1000 operating years. Inverter MTBF is about a week (1994 technology).
    - UPG 14kW inverter/tracker MTBF is 43 operating years.
    - Passive (piston-based) trackers have experienced reduced accuracy and increased seal failure after 5 years.
  - PVUSA: Scheduled O&M is 0.2-0.5¢/kWh, unscheduled is 0.05-0.4¢/kWh other than PCU, 0.2-5¢/kWh for PCU.
  - Recent large PV inverters: > 99% availability, 1.7 yr MTBF.
- **Installation/maintenance** - Economies of scale reduce per kWh costs. Commitment to maintenance is an issue.

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Remote Non-Hybrid Applications - Direct Power (Water Pumping)

- **Functional Requirements:** Provide sufficient water to tank for livestock.
- **Value of System**: Avoided cost of alternative power system, value of livestock served.
- Issues:
  - Minimal data: 1992 EPRI survey of 154 systems.
  - **Design issues**: Undersized systems due to lack of low-cost intermediate-sized submersible pump.
  - **Component reliability**: ~1 failure per system. Systems under 5 yrs old.
    - Defective parts, improper installation.
    - Pumps were 63% of failures.
    - Passive (balance) trackers and panels very reliable.
  - **Installation/Maintenance**: Half the owners performed maintenance.

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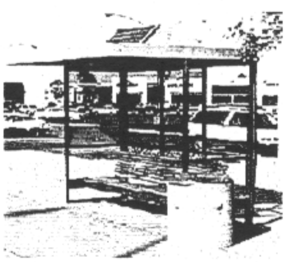
Remote Non-Hybrid - Battery Storage

- **Functional Requirements:** Provide regular load service through daily and seasonally varying weather without alternative power sources.



- **Value of System:**
  - High value due to high cost of alternative power systems and high value of service.
  - High value has made this the major existing market application sector, with potential for significant further markets.

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Remote Non-Hybrid - Battery Storage

- **Limited data:** due to dispersed remote systems. Some data from Colorado State Parks systems.
- **Design issues**:
  - Battery costs are major factor.
  - Battery performance (cycle-life and capacity) in deep-cycle, resource-constrained charging environments is poorly understood.
    - Battery cycle-life and system availability are very sensitive to:
      - battery size (depth of discharge or DoD),
      - charging variations (array size, seasonal insolation variations),
      - charge controller setpoints (coupling energy to the battery), etc.
  - Need ability to optimize design from a wide range of choices trading off capital cost, replacement cost, and O&M.

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Remote Non-Hybrid - Battery Storage

- **Design issues (cont.)**:
  - System integration issues: Design for Installation and Servicing
    - Few parts, labeled parts, simple layout, standard design, accessibility.
    - Design for vandalism environment.
    - Resistant to owner tampering (developing countries).
    - Design for maintenance of all components on same schedule.
- **Component Issues**
  - Battery maintenance: improve service interval.
  - Charge controller: Reliability info is anecdotal but indicates need for improved lightning protection, setpoint stability, and manufacturing quality control.
  - Load issues: low voltage dc ballasts and lights need improvement.
- **Installation/Maintenance**: Remote sites incur high transportation labor.

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Remote Hybrid Systems

- **Functional Requirements:** Provide regular load service through daily and seasonally varying weather.
- **Value of System:** Value of energy is high due to remote siting, however, PV energy cost competes with that from generator operating at full load efficiency.

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Remote Hybrid Systems

- **Design Issues**:
  - Optimal operational strategy when using PV in hybrid systems is not well understood.
    - A strategy is needed for generator operation to best use time-constrained PV energy and to fulfill lengthy battery equalization charge requirements while minimizing stress on the generator.
  - Experience is that multiple service calls are needed to field-tune the system to match controls with the generator and load during transfer from dc (battery/PV) to ac (generator) source under complex load conditions.
- **Component Reliability:**
  - Improved tolerance to transients by power processor is needed.
- **Operation/Maintenance**: Limited data.

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Conclusions

- A system-level approach to understanding PV reliability enables designing for sustainable systems.
- Present reliability data is limited and anecdotal.
- Different PV application sectors have different requirements in their Core Elements; design, component reliability, installation, and maintenance.

Do we know what we need to about PV systems to reduce levelized costs and increase markets?

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SOLUZ™

Mining the Data:

Learning Reliability Lessons from PV Leasing

John H. Rogers
SOLUZ, Inc.
November 1998

SOLUZ™ Solar Electric Energy Delivery

Overview

- SOLUZ Operations
- SOLUZ Reliability Data
  - What we have
  - What we can do with it
  - Why we care
- Next Steps

SOLUZ™ Solar Electric Energy Delivery

SOLUZ Operations

- Importer/Distributor/Retailer
  - Wholesale, retail, fee-for-service
  - FFS = financing and maintenance
- Stand-Alone PV - **SEED™**
  - 4 system sizes
  - Lighting, radio, TV
  - D.R. (1994) - 1,721 customers
  - Honduras (1998) - 150 customers

SOLUZ™ Solar Electric Energy Delivery

SOLUZ Operations

- Components
  - Modules - 7 manufacturers, 4 technologies
  - Batteries - 6
  - Controllers - 4
  - Lights - 4
  - Mount - 2

SOLUZ™ Solar Electric Energy Delivery

Soluz Reliability Data: What We Have

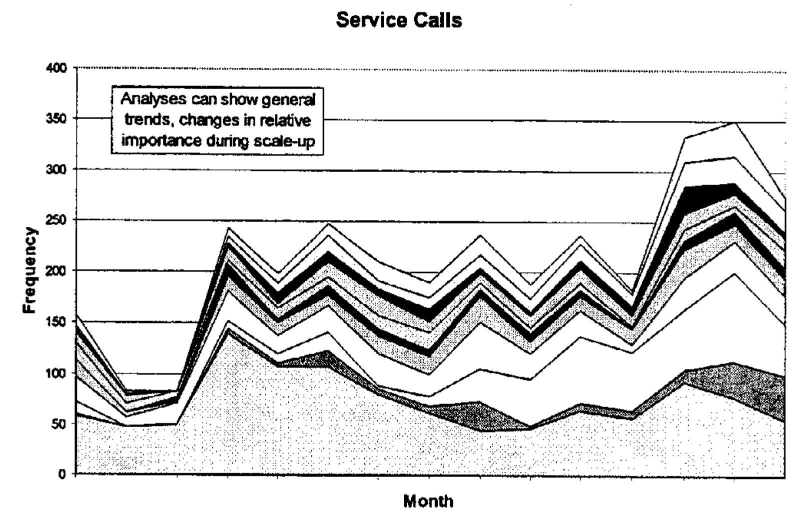
- "Mother Lode"
  - Installation data
  - Service calls
  - Long-term
- Limitations

SOLUZ™ Solar Electric Energy Delivery

Soluz Reliability Data: What We Can Do With It

- Big Picture
  - "Brute force" analyses
  - Pareto diagrams/prioritization
- Statistical Analyses
  - Configurations leading to failures
  - Correlations

SOLUZ™ Solar Electric Energy Delivery



SOLUZ™ Solar Electric Energy Delivery

Soluz Reliability Data: Why We Care

- Service to Customers <== ❋!
- Contribution Margin
  - Maintenance
  - Labor
- Ex: Battery Life, Lamp Life

SOLUZ™ Solar Electric Energy Delivery

Soluz Reliability Data: Analysis of Battery Life

- Base Case - 3 years
  - Financing = $1.35M additional
  - 5,000 customers >> 6,400 over 5 years
- 2 Years >> Additional Financing
  - 50% more financing to maintain ramp-up rate
- 4 Years >> Faster Ramp-Up, Greater $
  - 50% faster ramp-up
  - 85% greater retained earnings after 7 years

SOLUZ™ Solar Electric Energy Delivery

SOLUZ Reliability Data: Next Steps

- Where It Goes From Here
  - Design modifications
  - Financial projections
  - Feedback to manufacturers
  - PV GAP

SOLUZ™ Solar Electric Energy Delivery

SOLUZ Reliability Data: Next Steps

- How We Go Farther
  - Database
  - Automated data collection

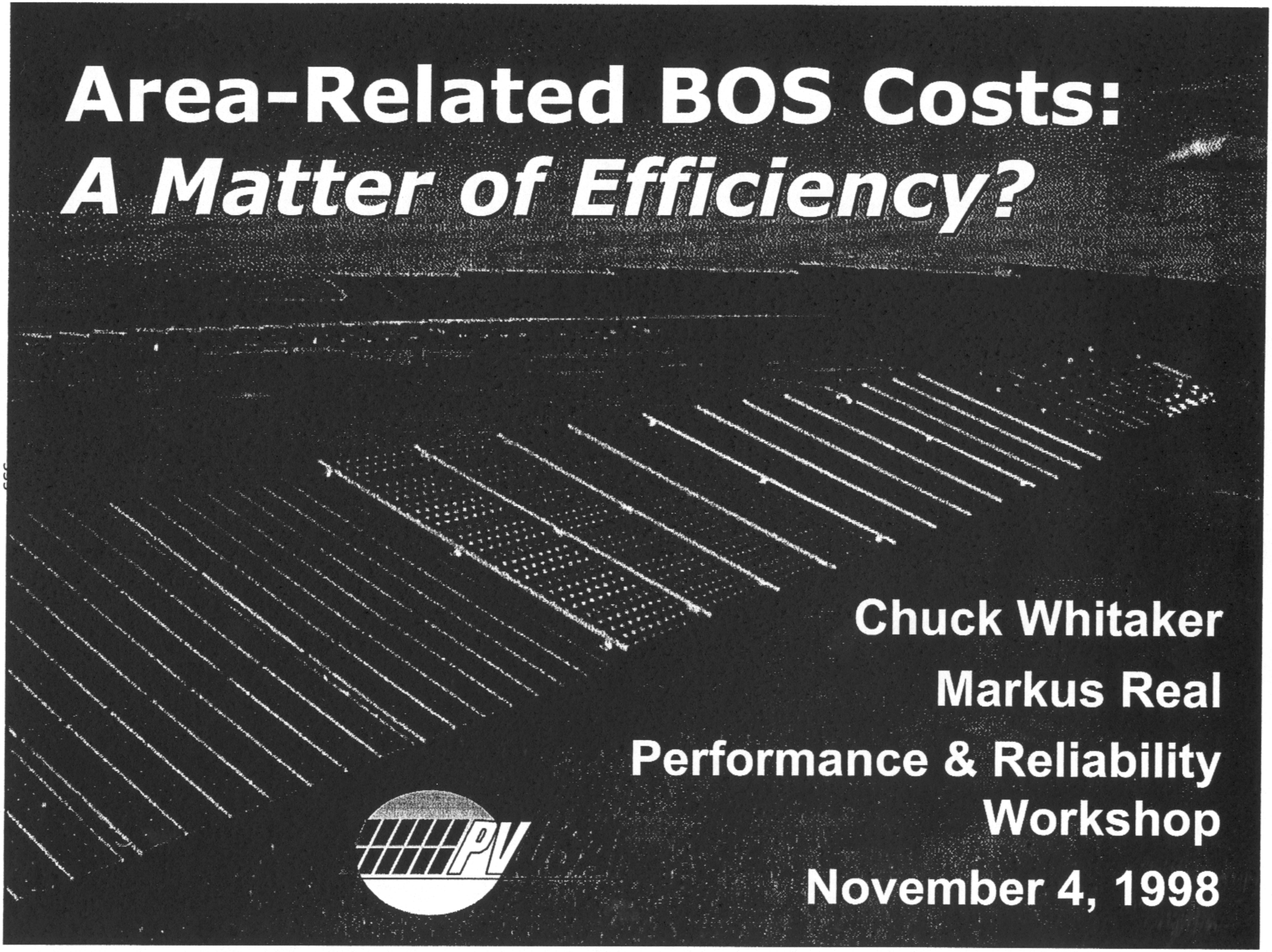
Analysis takes time, time takes money

SOLUZ™ Solar Electric Energy Delivery

SOLUZ Reliability Data

- ❋ Fee-For-Service Works
  - ✧ For customer
  - ✧ For company
  - ✧ For industry
- ❋ Gold Mine for Data
- ❋ Time = Money

SOLUZ™ Solar Electric Energy Delivery


Area-Related BOS Costs:
A Matter of Efficiency?
Chuck Whitaker
Markus Real
Performance & Reliability
Workshop
November 4, 1998
PV

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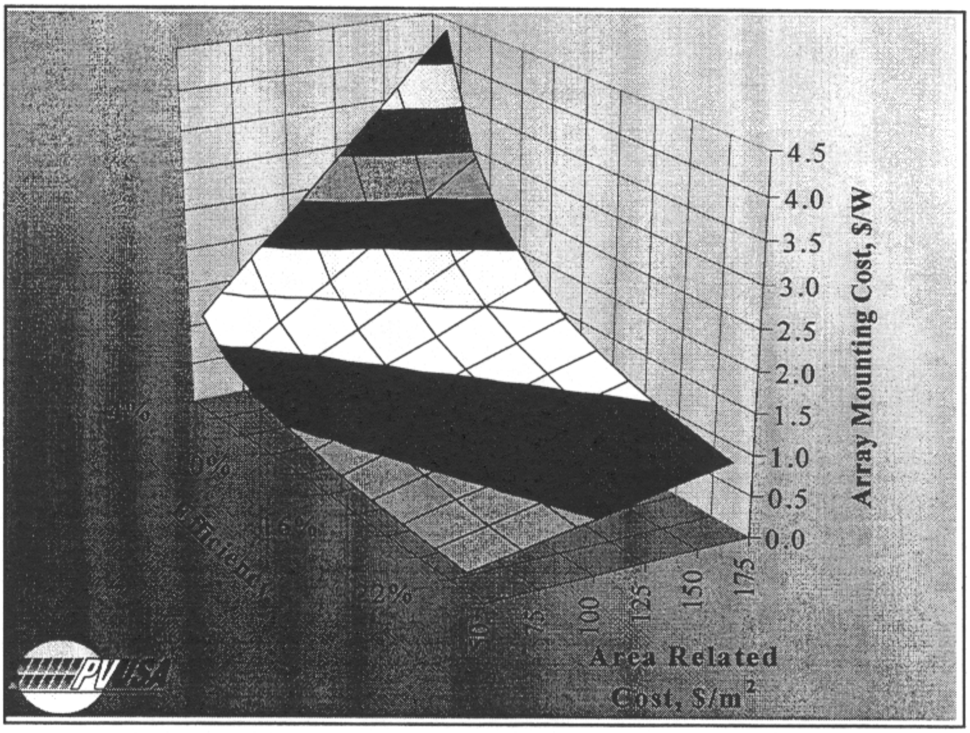
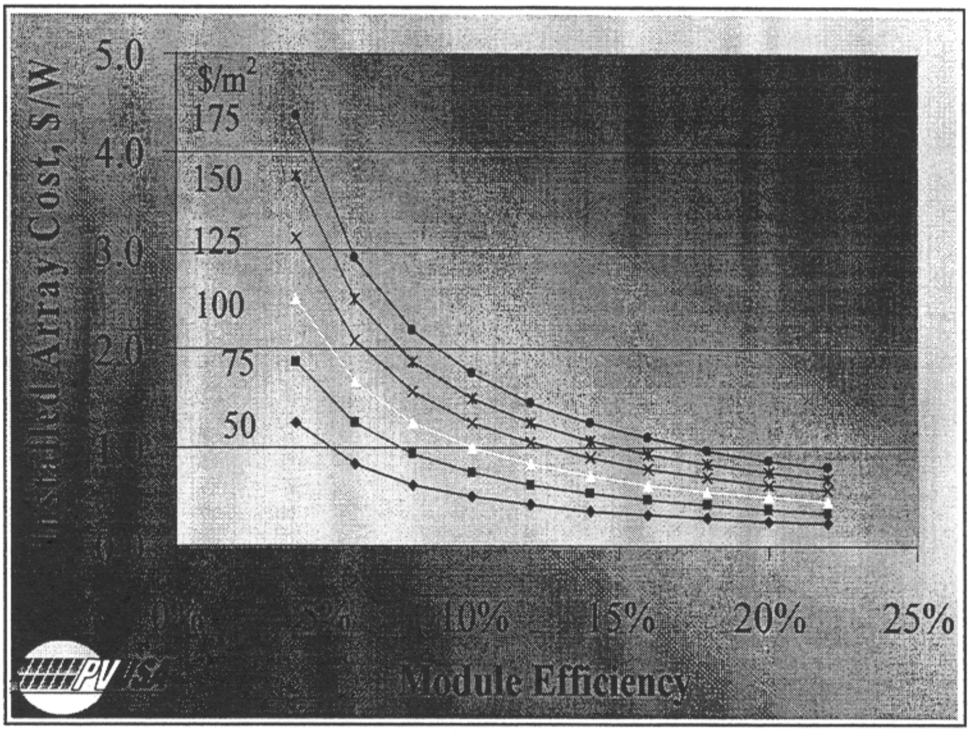
PVUSA



Array Mounting Cost, $/W
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Efficiency
10%
16%
22%
Area Related Cost, $/m^2
100
125
150
175
PV USA



Installed Array Cost, $/W
5.0
4.0
3.0
2.0
$/m^2
175
150
125
100
75
50
10%
15%
20%
25%
Module Efficiency
PV USA

Cost Categories

- **Area-related BOS:** Land, site prep; foundation, structure, array mechanical hardware and on-site labor; module installation; dc wiring, misc. hdw and on-site labor; associated design labor, misc. equipment and overheads. *$/m²* or *$/Watt* for a specific efficiency.
- **Non-area-related BOS:** PCU; AC switchgear and wiring; instrumentation, control, monitoring (DAS/SCADA); associated construction labor, equipment, overheads; associated design labor. *$/Watt.*
- **PV Array:** Modules (incl. internal diodes etc). *$/Watt.*

PVUSA

PVUSA Kerman 500 kW

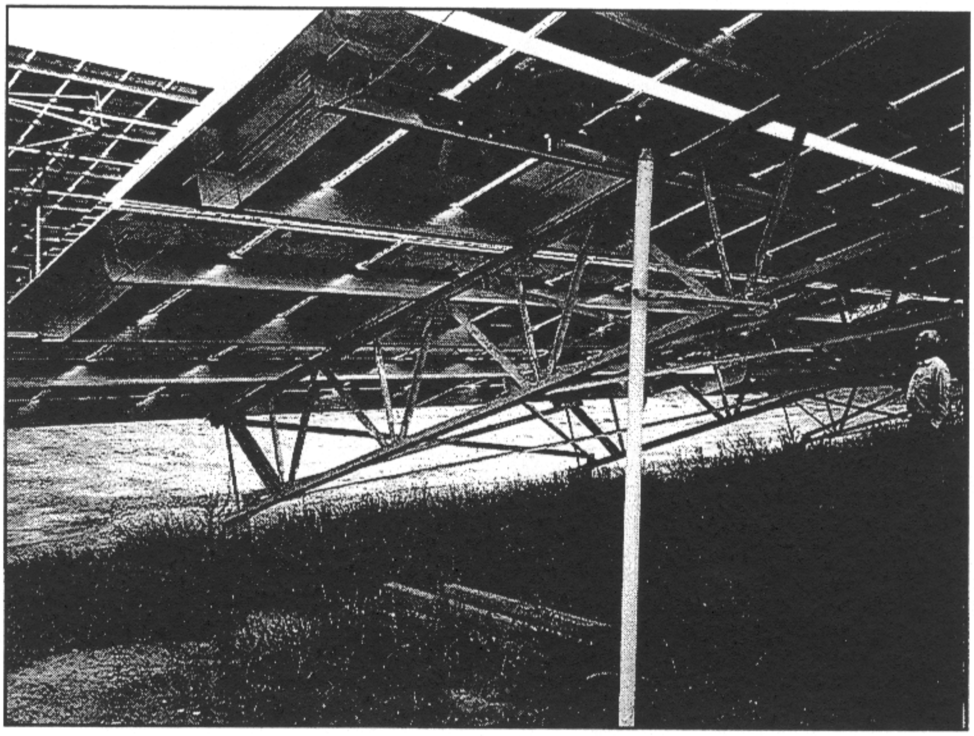
	Actual (Less "Research")				Improved			
	$	$/Watt	$/m2	%	$	$/Watt	$/m2	%
Area Related								
Owner On-site labor	106,220	0.21	20.34	1.8%	98,282	0.20	18.82	1.7%
Land & Site Prep	211,109	0.42	40.43	3.5%	164,375	0.33	31.48	2.8%
Foundation	110,905	0.22	21.24	1.8%	110,905	0.22	21.24	1.9%
Structure	403,575	0.81	77.29	6.7%	403,575	0.81	77.29	6.8%
DC Wiring	104,341	0.21	19.98	1.7%	104,341	0.21	19.98	1.8%
Misc BOS	496,363	0.99	95.07	8.2%	496,363	0.99	95.07	8.4%
	1,432,513	2.87	274.36	23.8%	1,377,841	2.76	263.89	23.2%
Modules	2,626,380	5.25	503.02	43.6%	2,626,380	5.25	503.02	44.3%
Non-area Related								
PCU	545,378	1.09	104.45	9.1%	545,378	1.09	104.45	9.2%
AC electrical	25,194	0.05	4.83	0.4%	25,194	0.05	4.83	0.4%
Other (bldgs, SCADA, etc)	651,958	1.30	124.87	10.8%	637,757	1.28	122.15	10.8%
Owner Home Office	737,003	1.47	141.15	12.2%	714,233	1.43	136.79	12.1%
	1,959,533	3.92	375.30	32.6%	1,922,562	3.85	368.22	32.4%
Total	**6,018,425**	**12.04**	**1153**		**5,926,782**	**11.85**	**1135**	

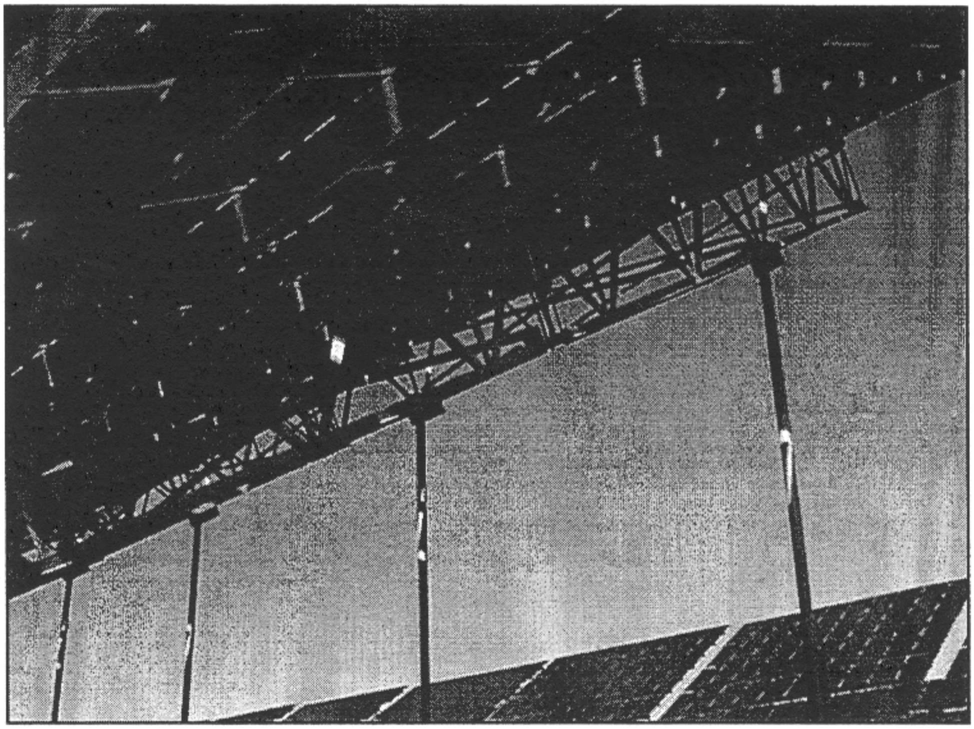
PVUSA

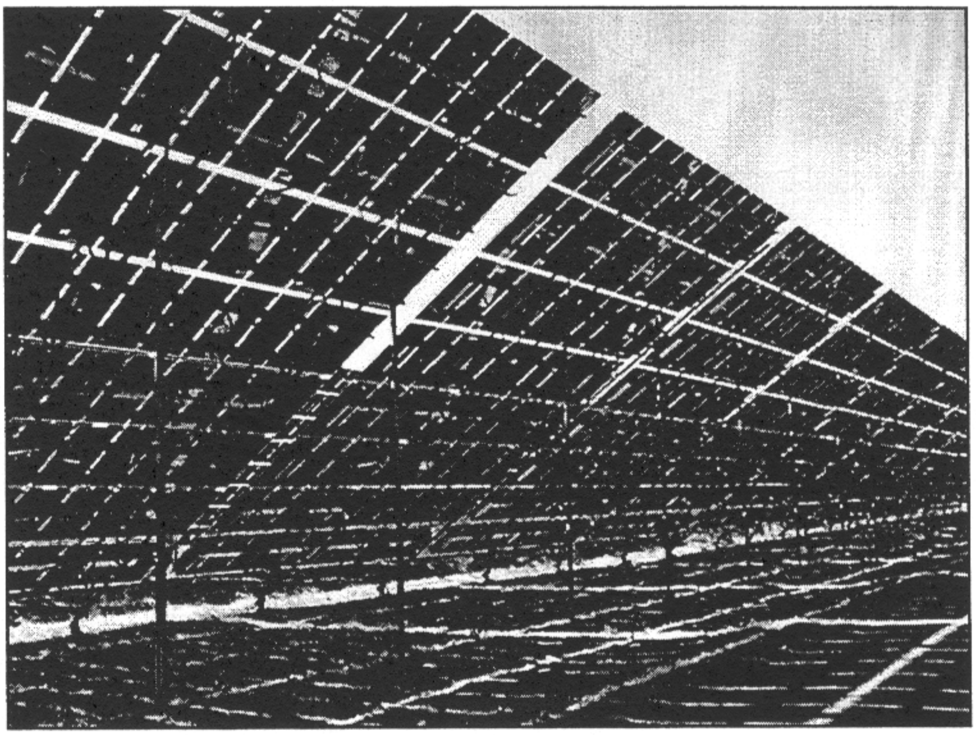
PVUSA Structure Costs

	Siemens US-1	IPC US-1 ($/m^2)	APS US-1
Array Size	1690 m^2	2443 m^2	11520 m^2
Foundation	45.09	32.47	13.74
Labor	21.33	11.92	6.84
Materials	23.76	20.55	6.90
Structure	115.18	104.14	19.77
Labor	9.14	6.07	4.06
Materials	106.05	98.06	15.71
TOTALS	160.27	136.60	33.52

PVUSA







TEAM-UP System Prices

TEAM-UP Round		
1	2	3
System Prices \$/W		
\$14.21	\$11.76	\$9.24
\$10.20	\$8.71	\$8.85
\$10.08	\$7.14	\$8.50
\$7.43	\$7.00	\$8.40
\$7.00	\$6.30	\$8.25
\$6.80	\$6.17	\$8.24
\$6.77	\$6.00	\$7.95
\$6.59	\$5.36	\$7.78
\$5.88		\$7.60
		\$7.23
		\$6.75
		\$6.24
		\$6.15
		\$6.01

PVUSA

SMUD PV Pioneer Costs

Year	Installation		Modules		PCU		Module DC to AC		TOTAL		Owner	
	\$/W	\$/m²	\$/W	\$/m²	\$/W	\$/m²	\$/W	\$/m²	\$/W	\$/m²	\$/W	\$/m²
1993	\$1.87	\$187	\$4.63	\$463	\$1.20	\$120			\$7.70	\$770	\$1.08	\$108
1994	\$1.23	\$105	\$4.00	\$340	\$1.00	\$85			\$6.23	\$530	\$0.90	\$77
1995									\$5.98	\$598	\$0.89	\$89
1996	\$1.20	\$108	\$3.08	\$277	\$0.65	\$59	\$0.31	\$28	\$5.24	\$472	\$0.67	\$60
1997	\$1.18	\$106	\$2.50	\$225	\$0.57	\$51	\$0.25	\$23	\$4.50	\$405	\$0.59	\$53
1998	\$1.28	\$64	\$2.25	\$113	\$0.55	\$28	\$0.23	\$12	\$4.31	\$216	\$0.30	\$15

All Watts in PTC ac

PVUSA

Swiss Roof Top Systems

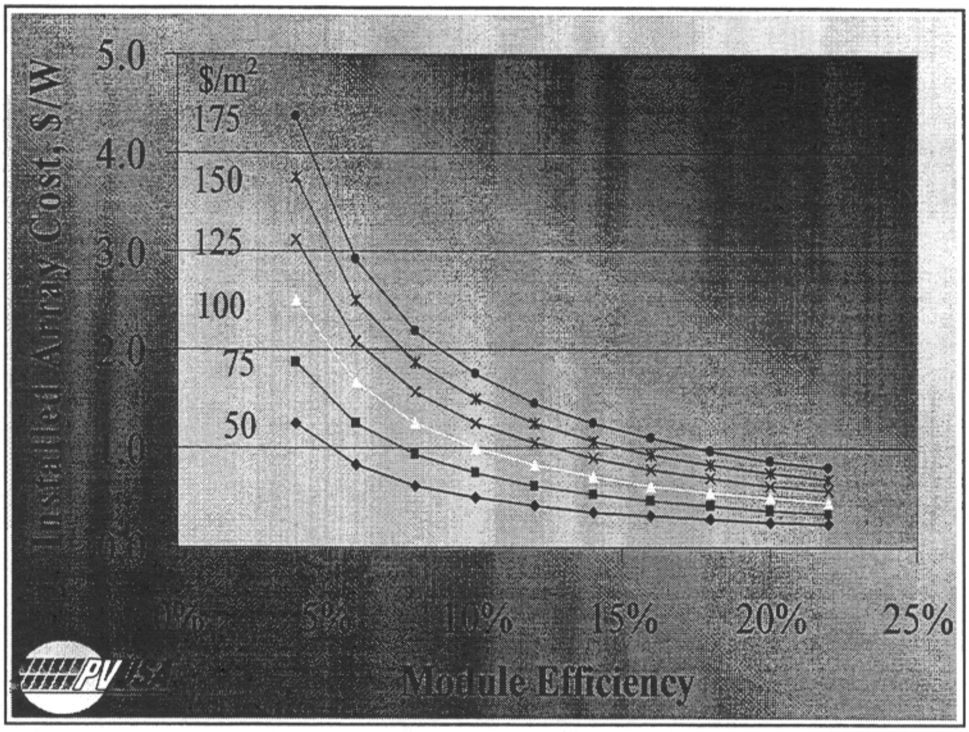
System	Materials	Labor	Total
Balasted Flat Roof	45.52	47.09	92.61
Solar Roof Tile	91.43	25.00	116.43

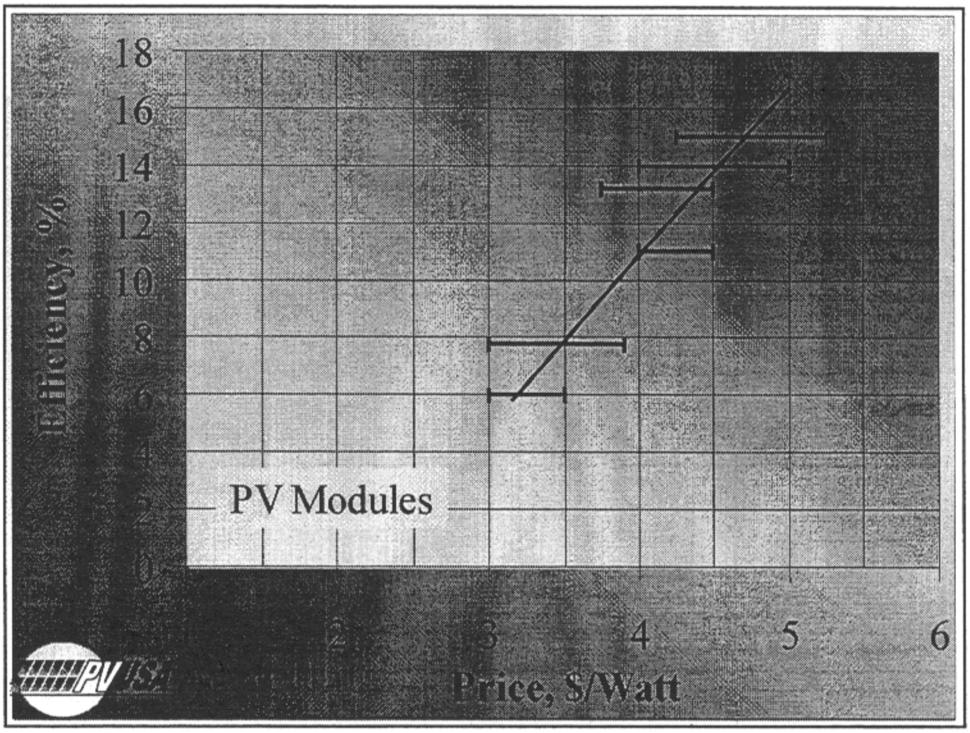
PVUSA

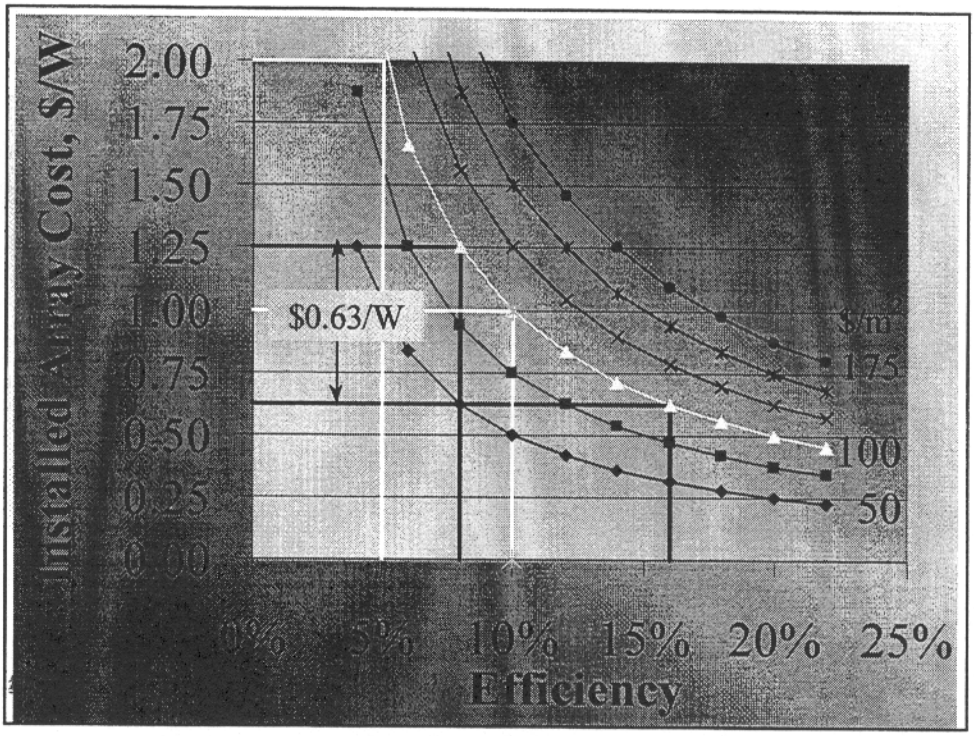
The "$6/Watt" System

Area Related	"Improved"	$	$/Watt	$/m²	%
Owner On-site labor	98,282	30,000	0.06	5.75	1.0%
Land & Site Prep	164,375	90,000	0.18	17.24	3.0%
Foundation	110,905	75,000	0.15	14.36	2.5%
Structure	403,575	130,000	0.26	24.90	4.3%
DC Wiring	104,341	50,000	0.10	9.58	1.7%
Misc BOS	496,363	100,000	0.20	19.15	3.3%
	1,377,841	475,000	0.95	90.97	15.8%
Modules	2,626,380	1,750,000	3.50	335.17	58.3%
Non-area Related					
PCU	545,378	250,000	0.50	47.88	8.3%
AC electrical	25,194	25,000	0.05	4.79	0.8%
Other (bldgs, SCADA, e	637,757	250,000	0.50	47.88	8.3%
Owner Home Office	714,233	250,000	0.50	47.88	8.3%
	1,922,562	775,000	1.55	148.43	25.8%
Total	**5,926,782**	**3,000,000**	**6.00**	**575**	

PVUSA


Installed Array Cost, $/W
5.0
4.0
3.0
2.0
1.0
0.0
$/m²
175
150
125
100
75
50
5%
10%
15%
20%
25%
Module Efficiency


Efficiency, %
18
16
14
12
10
8
6
4
2
0
PV Modules
2
3
4
5
6
Price, $/Watt



Conclusions

- There are a multitude of items buried in "Area-Related Costs"
- PV People don't like to share
- You can bust the bank with area related costs
- You can get to a $6/Watt system with an 8% efficient system, but probably not with a 5%

PVUSA

Will AC Modules Reduce System Lifecycle Costs?

Edward C. Kern, Jr.
Ascension Technology, Inc.

1998 PV Performance and Reliability Workshop
November 3-5 Cocoa Beach, Florida

No. Wrong Question!

- Rather, what makes AC modules appealing over options with field wired dc circuits?
  - Simple; plug together, ac branch circuit, done!
  - Elegant: Sunlight to Sinewaves
  - Silent: acoustic and electromagnetic
  - Compact: everything on the roof
  - Affordable: can start small

11/16/98 Ascension Technology, Inc. 2

Life Cycle Cost

$$L(\theta)=\sum_{n=1}^{N}\iint_{\theta}\left[1+\prod_{i}^{\infty}D_{oe}(1+i)\right]$$

where

$$D_{oe}=(E_e\,\mathrm{R_e}-UPV_g-NC_{pv})$$

$$i=\sqrt[n]{N_rE_l-S_nL_a}$$

11/16/98 Ascension Technology, Inc. 3

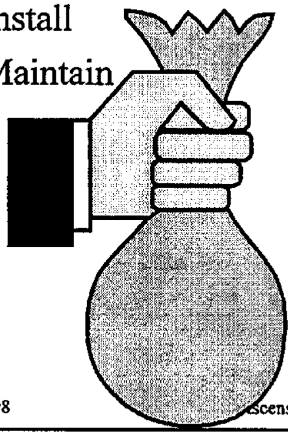
Lifecycle Cost Logic?

- A customer that invests in capital goods with 20+ year simple payback to avoid cheaper, *proven* alternatives?
- A manufacturer in a 25-year old industry that incurs 20-year product liabilities?
- An industry that pitches its products by claiming that next year's prices will be *lower*?

11/16/98 Ascension Technology, Inc. 4

Lifecycle Costs and Benefits

- Purchase
- Install
- Maintain



- Electricity

11/16/98 Ascension Technology, Inc. 5

Our Costs, Customer's Benefits

- Manufacturing
- Installation
- Call backs
- Warrantee
- Metering
- Monitoring
- Inspection
- Maintenance/repair

- Kilowatt-hours
- Kilowatts
- Back-up power
- Independence
- Environment

11/16/98 Ascension Technology, Inc. 6

Manufacturing Costs ($/W ptc,ac)

	AC Module		DC Module	
Manufacturer	**Low**	**High**	**Low**	**High**
Laminates	$ 5.00	$ 6.00	$ 5.00	$ 6.00
Inverters	$ 1.00	$ 3.00	$ 0.75	$ 1.00
Connectors	$ 0.10	$ 0.15	$ 0.10	$ 0.15
Electrical	$ 0.50	$ 1.00	$ 0.75	$ 1.50
Cost of Goods	**$ 6.60**	**$ 10.15**	**$ 6.60**	**$ 8.65**

11/16/98 Ascension Technology, Inc. 7

Manufacturer Expenses

	AC Module			DC Module		
	Low	**High**		**Low**	**High**	
R&D costs	$ 0.26	$ 0.41	4%	$ 0.26	$ 0.35	4%
G&A costs	$ 0.26	$ 0.41	4%	$ 0.26	$ 0.35	4%
M&S costs	$ 0.33	$ 0.51	5%	$ 0.33	$ 0.43	5%
Warrantee costs	$ 0.20	$ 0.30	3%	$ 0.20	$ 0.26	3%
Inventory costs	$ 0.26	$ 0.41	4%	$ 0.26	$ 0.35	4%
Expenses	**$ 1.32**	**$ 2.03**		**$ 1.32**	**$ 1.73**	

11/16/98 Ascension Technology, Inc. 8

Manufacture's Pricing

	AC Module			DC Module		
	Low	High		Low	High	
Total	$ 7.92	$ 12.18		$ 7.92	$ 10.38	
Profit	$ 0.40	$ 0.61	5%	$ 0.40	$ 0.52	5%
Wholesale	**$ 8.18**	**$ 12.79**		**$ 8.18**	**$ 10.90**	
Shipping	$ 0.10	$ 0.20		$ 0.15	$ 0.20	

11/16/98 Ascension Technology, Inc. 9

Dealer/Installer Pricing

	AC Module			DC Module		
Dealer/Installer	Low	High		Low	High	
Cost of Goods	$ 8.28	$ 12.99		$ 8.33	$ 11.10	
Warehousing	$ 0.08	$ 0.13	1%	$ 0.08	$ 0.11	1%
G&A	$ 0.25	$ 0.39	3%	$ 0.25	$ 0.33	3%
M&S	$ 0.25	$ 0.39	3%	$ 0.25	$ 0.33	3%
Installation	$ 0.50	$ 1.00		$ 1.00	$ 2.00	
Metering	$ 0.10	$ 0.15		$ 0.10	$ 0.15	
Total	$ 9.46	$ 15.05		$ 10.02	$ 14.03	
Profit	$ 0.47	$ 0.75	5%	$ 0.50	$ 0.70	5%
Retail Price	**$ 9.94**	**$ 15.80**		**$ 10.52**	**$ 14.73**	

11/16/98 Ascension Technology, Inc. 10

Annual Operating Costs

	AC Module			DC Module		
Service	Low	High		Low	High	
Monitoring	$ 0.10	$ 0.16	1%	$ 0.11	$ 0.15	1%
Inspection	$ 0.10	$ 0.16	1%	$ 0.11	$ 0.15	1%

11/16/98 Ascension Technology, Inc. 11

Will AC Modules Reduce Life Cycle Cost? Yes.

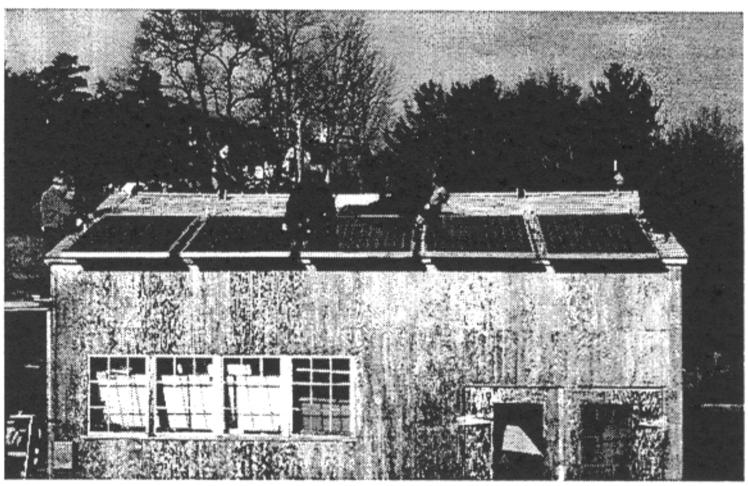
- Reduce installers' administrative, design and installation costs for dc wire runs, switchgear and power conversion equipment
- Reduce parts counts and eliminate dc wiring
- Keys: volume manufacturing, factory integration and **unmatched reliability.**

11/16/98 Ascension Technology, Inc. 12

SunSine™ 300

11/16/98 Ascension Technology, Inc. 13

SunSine™ 300



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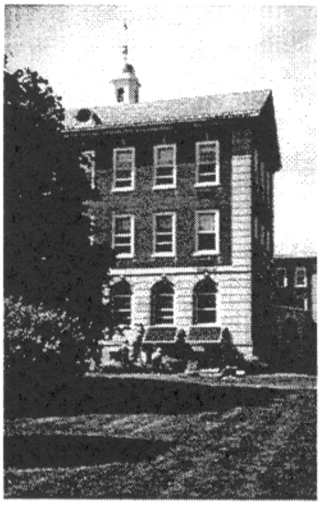
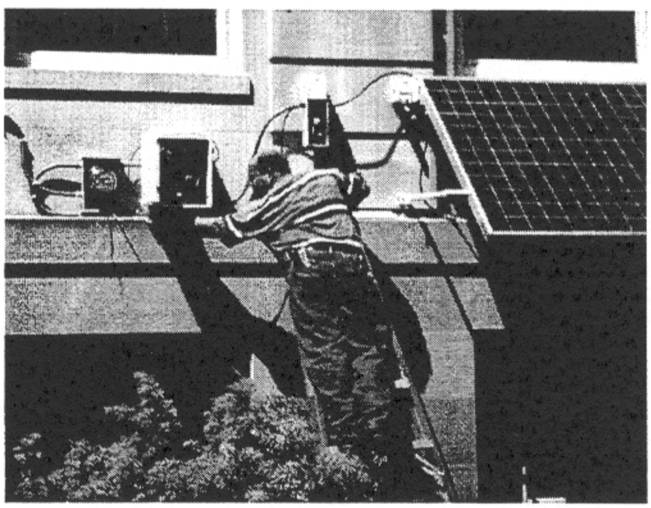
SunSine™ 300



- WallJack™ mounting designed for use with south facing walls
- Specially developed for school applications where visibility to students and community is critical

11/16/98 Ascension Technology, Inc. 15

SunSine™ 300



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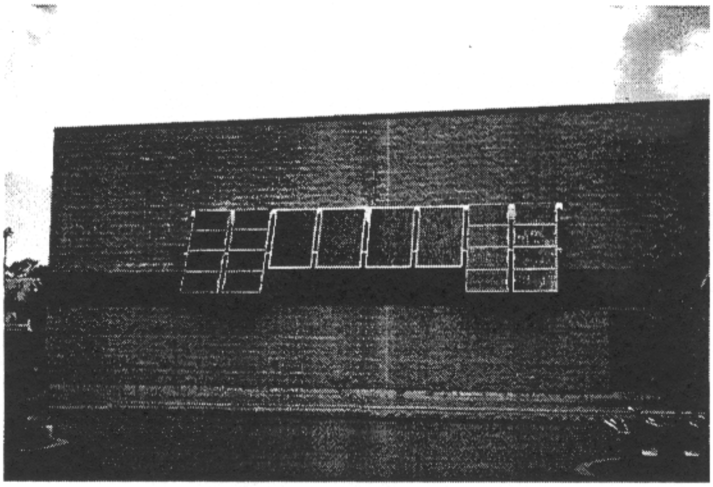
SunSine™ 300



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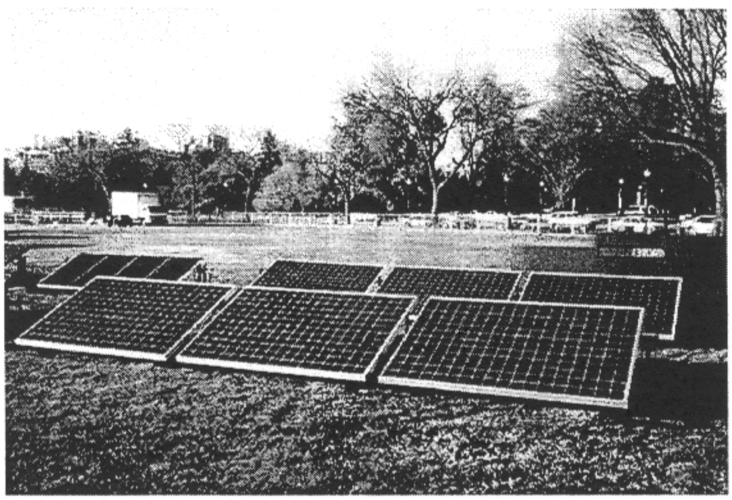
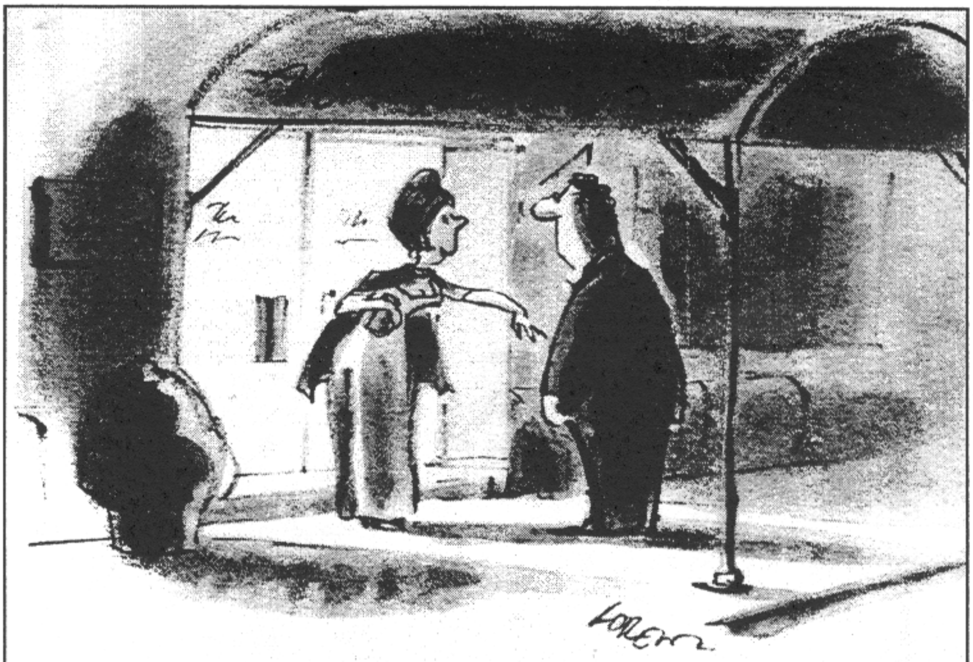
SunSine™ 300



11/16/98 Ascension Technology, Inc. 18



"Thanks for a wonderful evening, Eric, and I'll always cherish what you told me about photovoltaic cells."

Designing Systems for Performance and Reliability

Trent Duncan, Bureau of Land Management, Utah State Office, (801) 539-4090

Introduction:
Trent Duncan
Bureau of Land Management
Utah State Office

Over the last 3 years I have coordinated the Renew the Public Lands partnership between BLM and the US Department of Energy Office of Photovoltaic and Wind Technology, through the Photovoltaic Systems Assistance Center at Sandia National Laboratories. I am truly amazed and grateful for the enthusiasm and support of Hal Post and Mike Thomas as my colleagues and I have tried to meet the goals of the partnership. I do need to tell them that it will take more than sunshine to renew the government

I hope to offer a BLM perspective on Designing for Performance and Reliability. I hope the systems with which I am involved, can survive with the same longevity as the bristle cone pine in the photo

I have identified 3 keys to successful and reliable BLM projects.

1. Advocate of technology and users who believe PV will work.
2. Standardized systems purchased as "ready-to-install" kits.
3. Installation by local maintenance staff and users.

The BLM has developed a total of 64 projects under the partnership. We have developed a method for designing, purchasing, installing and operating which meets the needs and culture of the agency.

- 25 facility power
- 26 water pumping
- 13 lighting systems

The largest are 2.5kw facility power systems, the smallest are 10 watt weather monitoring systems.

- Host systems: Volunteers with RV or use BLM RV. 384 Watt system (about 1kwhr/day) We have seen reduction in vandalism in one year greater than the cost of the PV system.

- Facility Power Systems. The remote stations typically are occupied during the week by scientists, range technicians, wildlife specialists, wilderness rangers, river rangers maintenance technicians and volunteers. The systems need to provide reasonable comforts for the users without requiring a great deal of knowledge about the operation of the equipment. Operation procedures require a reasonable amount of energy awareness, and conservation. We cannot afford to have a highly trained technician on site. We use a central person or local PV industry to provide maintenance.

Water pumping systems are generally for wildlife and livestock grazing on public lands, a few are for potable water at campgrounds or field stations. The systems must operate unattended for several months at a time.

Lighting systems for signs, restrooms and parking facilities. Vandalism and theft are acute problems for which we have no simple solutions for. Pre-packaged system from a vendor have been the most successful.

Design method:
Site assessment.

- Meet with personnel at the site and discuss current power use, needs, life style, loads
- identify possible array, battery, powercenter and inverter locations.
- identify current electrical generation method (engine generator or in some cases inadequate PV) (generators are typically run for a few hours a day due to fuel and maintenance costs and noise. I have found only 1 generator in over 30 sites that is operated 24hrs/day. The opportunities and quality of life improvements from a 24hr/day power are greatly appreciated by the users.)
- Discuss loads and identify energy efficiency opportunities and lifestyle changes necessary to optimize the cost effectiveness of using PV. In each case, the PV system is sized significantly less than the "Wish list". We have had to look at simply providing power for the necessities of living. The users then must live within the power provided.

Standard System Designs :

Perform a load analysis. Base system sizing on actual loads and past experience with similar sized facilities. A sandwash system, 1½ sandwash or two sandwash. The array size is increased or decreased based on location and seasons of use.

Our standard design consists of UL listed components when available and the following

- 64W modules - durability and flexibility of use in different applications.
- Powercenter - We have found that battery voltage, array current and load current are the most valuable items to monitor fro these types of systems.
- Sinewave Inverter - selected due to generator control and efficiency
- Valve regulated batteries - lack of dedicated and qualified maintenance to properly maintain flooded batteries.

Standard specifications have been developed which are easily tailored to meet the specific site conditions in terms of array mounting, battery type and number of inverters. These specifications for facility power and water pumping can be found in the appendix of the Renew the Government publication.

Photo of specs.

The original specifications were developed in order to purchase 10 portable power systems for campground hosts. Later the specifications were modified for water pumping. Pump size and array size is left up to the supplier based on TDH, daily water requirements, location and season of use. Easy to check instantaneous water rate for acceptance test. The facility power systems include specific numbers of modules, batteries, inverters etc.

The equipment and standards are specified and the supplier is responsible to configure the balance of the system and supply the equipment, conductors etc.. in a ready to install kit. A complete installation and operation manual is also required.

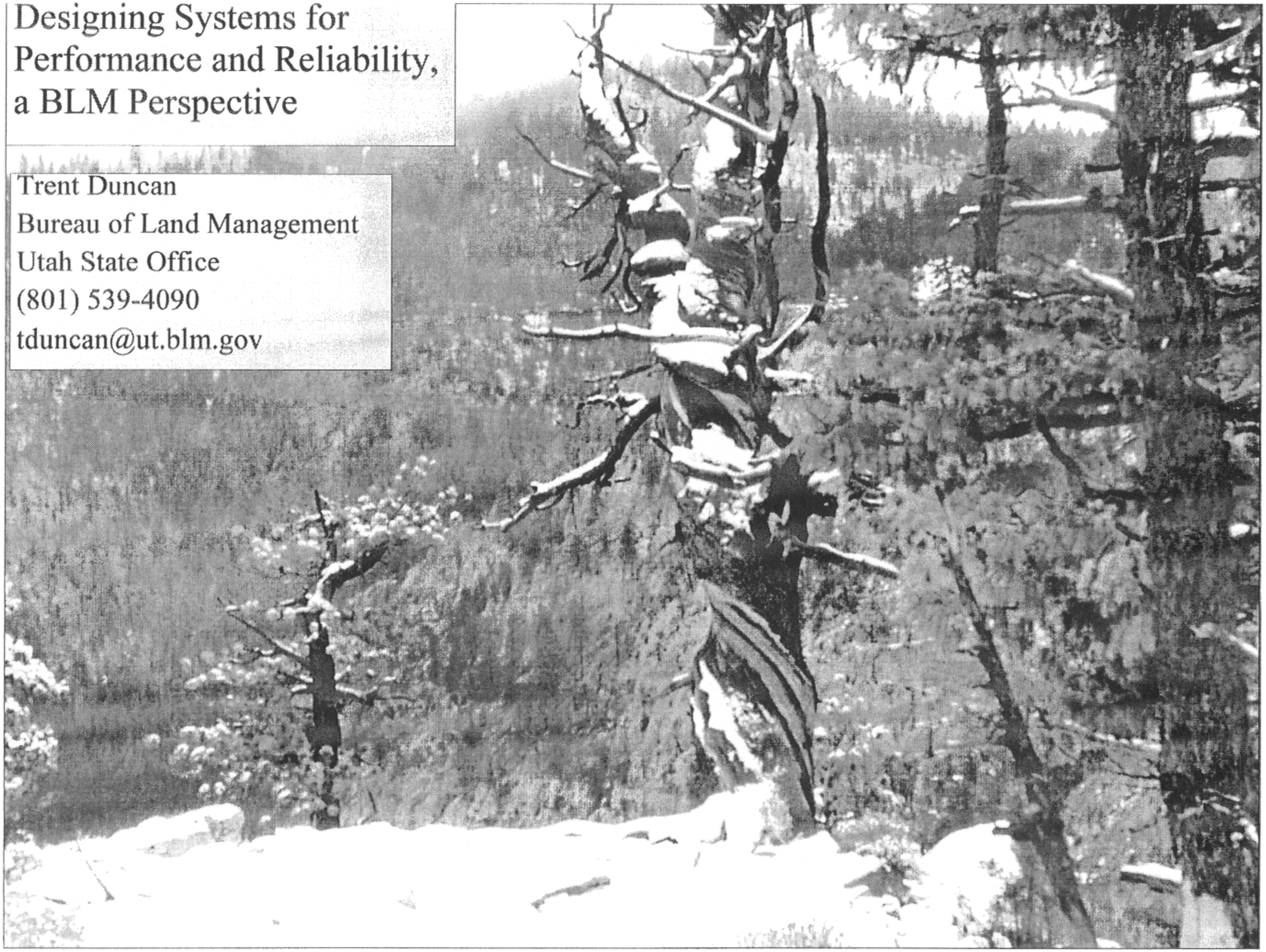
We have received excellent service from APC; host system is now a standard item in their GSA catalog, Photocom; supplying submersible centrifugal pumps and Solar Depot suppling facility power systems. In each case the purchase was awarded to the lowest bidder meeting the specifications.

Photo of installation in Parriette:

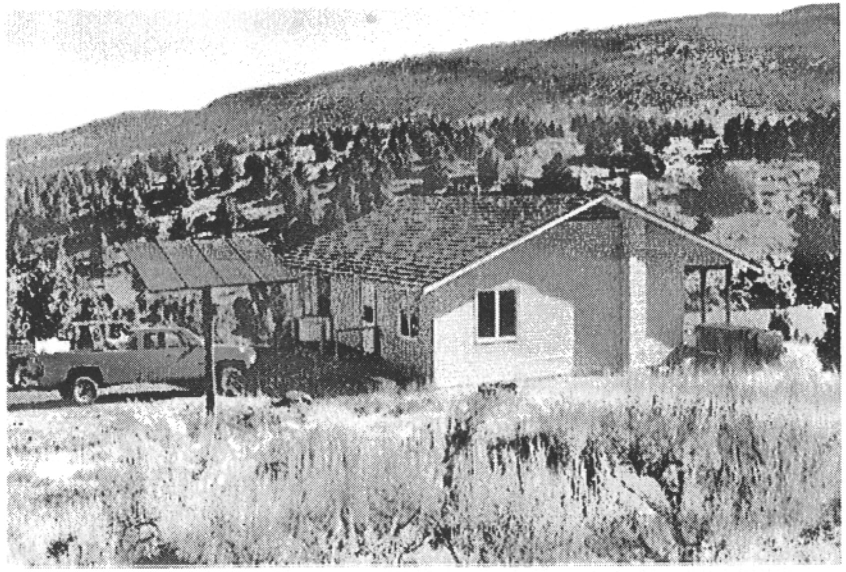
- By involving the local office, system users, and maintenance technicians in the installation we are able to provide productive hands-on-training. Sometimes we have invited the vendor to conduct an on-site training session.
- Buy-in, and develop greater understanding of system and its operation.
- more familiar with manual. After walking through the programming of an inverter one technician, he was able to trouble shoot a later problem with the system. It was obvious to me that he was understanding the manuals and the equipment.

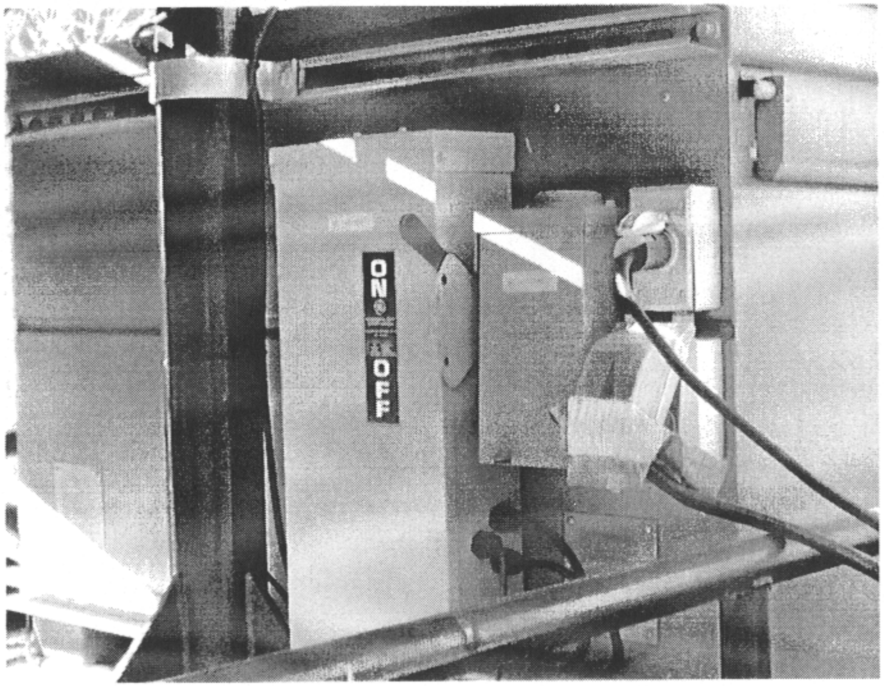
BLM lessons learned...

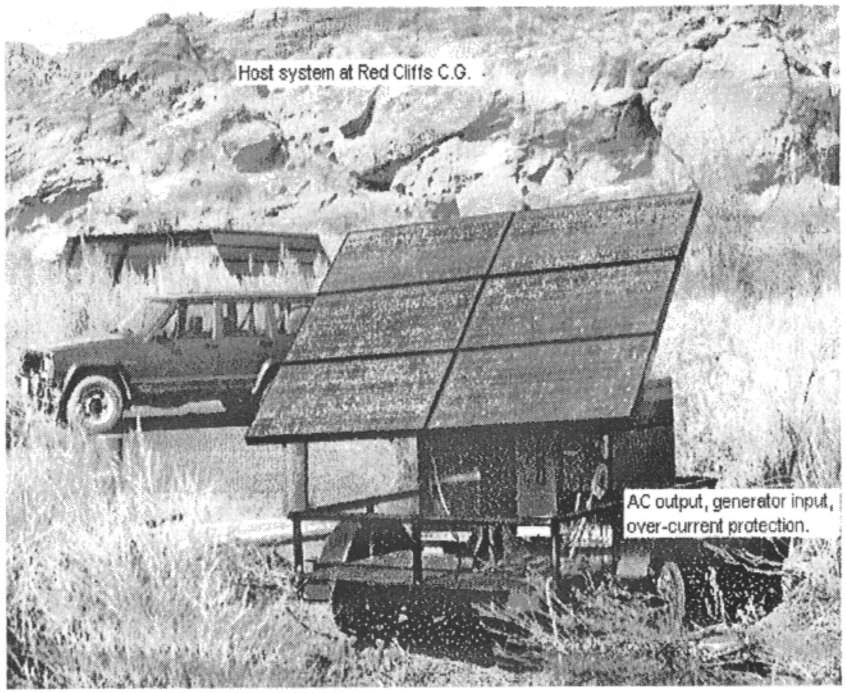
- wilderness rangers
- loads grow and shrink
- doesn't work
- need ribs


Designing Systems for
Performance and Reliability,
a BLM Perspective
Trent Duncan
Bureau of Land Management
Utah State Office
(801) 539-4090
tduncan@ut.blm.gov

Keys to Successful BLM Projects:
1. Advocate of technology and users who believe PV will work.
2. Standardized systems purchased as "ready-to-install" kits.
3. Installation by local maintenance staff and users.

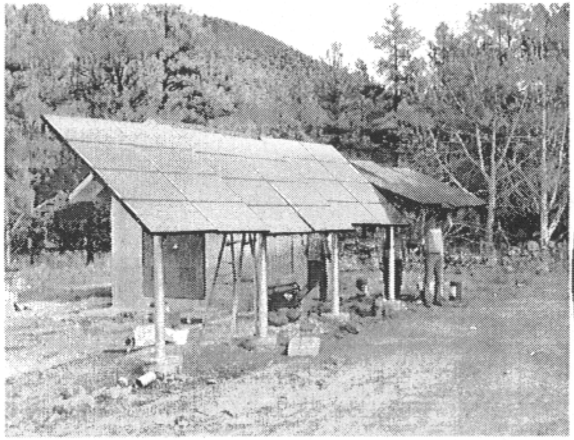


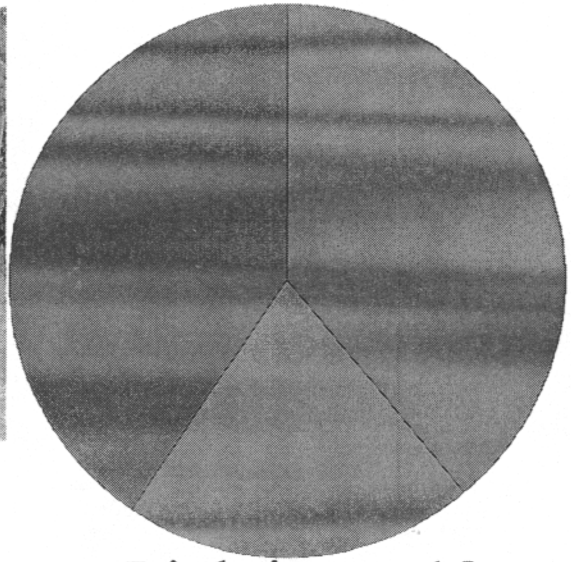




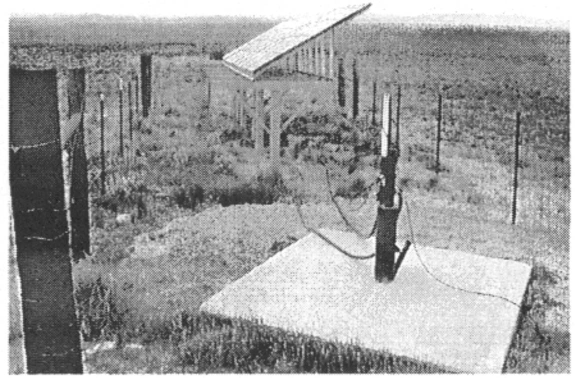
Renew the Public Lands Photovoltaic Projects

Facility Power - 25

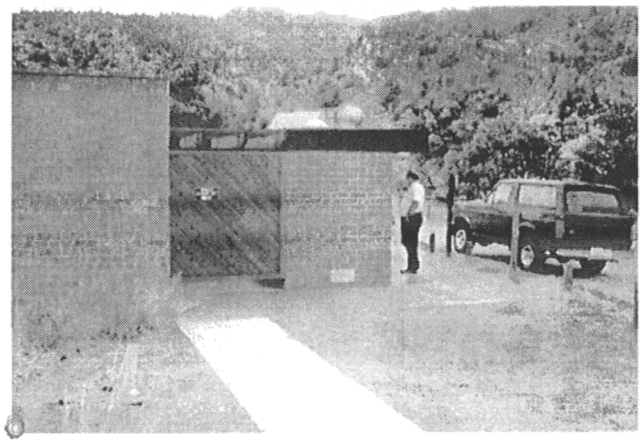


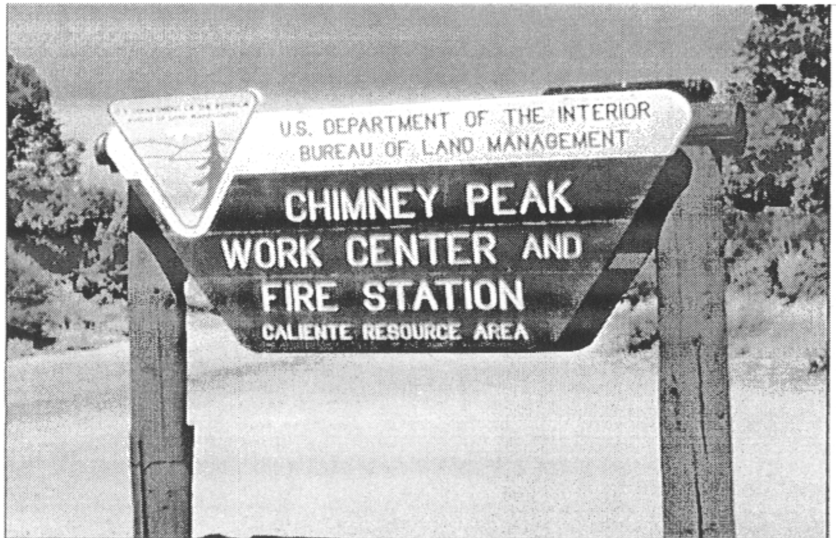


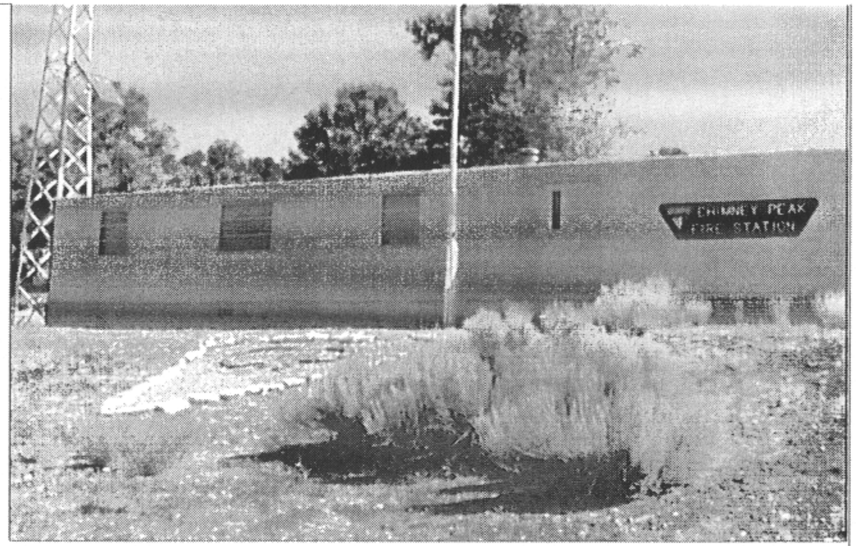
Water Pumping - 26

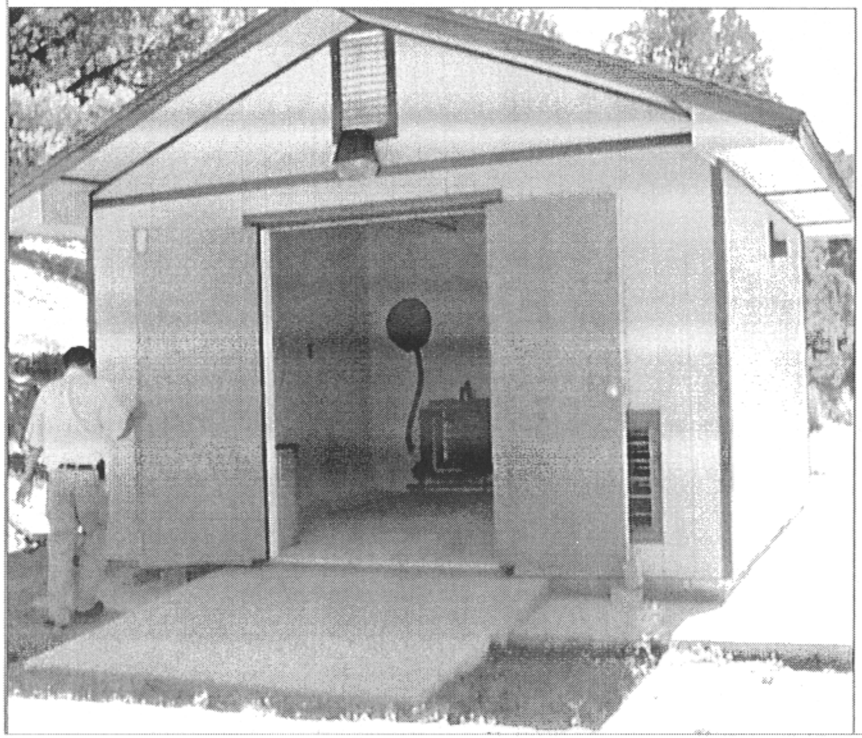


Lighting - 13



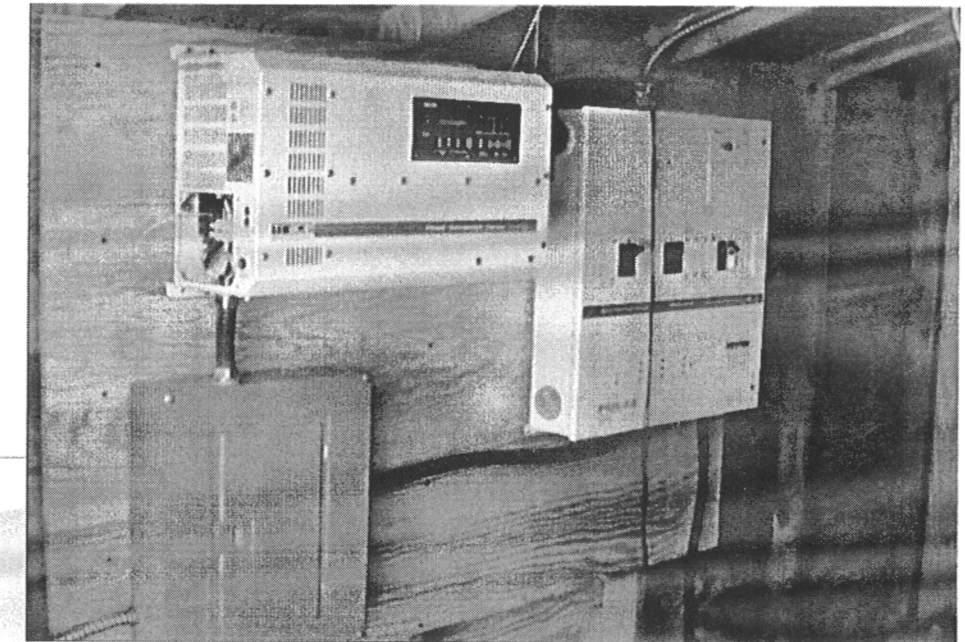






Site Asssessment includes identification of the following:
- Users, needs, lifestyle, loads
- Array, battery and control locations
- Current electrical generation methods
- Energy efficiency and conservation opportunities

Basic Building Blocks:
64 Watt Modules
Powercenter
Sinewave Inverter
Valve Regulated Batteries



Standard Specifications

PHOTOVOLTAIC POWER SYSTEM

PART 1: GENERAL

1.01 SUMMARY:

A. Provide four photovoltaic (PV) power systems capable of supplying alternating current as specified complete with PV modules, support racks, power panel, inverter(s), equipment supports, related wiring and other items required ready for government installation. The PV power systems will be used to provide electrical power for remote field stations.

1.02 REFERENCES:

A. National Fire Protection Association:

NFPA 70-96	National Electrical Code

1.03 SUBMITTALS:

A. General: Submittals include design computations, shop drawings, manufacturers' literature, as-built drawings, samples, and maintenance manuals. Deliver submittals to Trent Duncan, P.O Box 45155, Salt Lake City, UT 84145-0155, allow 5 working days for review.

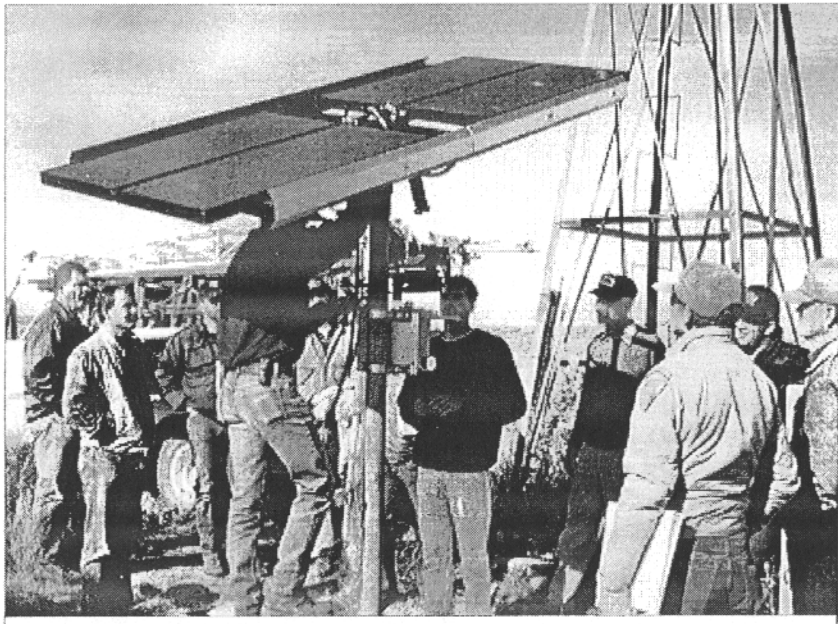
B. Required Submittals: Submit 2 Copies of the following,

1. Electrical diagram and installation drawing of the complete photovoltaic power system showing all major components provided, conductor sizes, types and lengths.
2. Submit catalog data on all equipment with complete description of components; including photovoltaic modules, batteries, inverter, power panel, panelboard, mounting hardware, fuses, cables, conductors, connectors, and all other related equipment.
3. Detailed operation and maintenance manual of complete photovoltaic system as outlined in Operation and Maintenance Data.

2.10 EQUIPMENT SUMMARY TABLE:

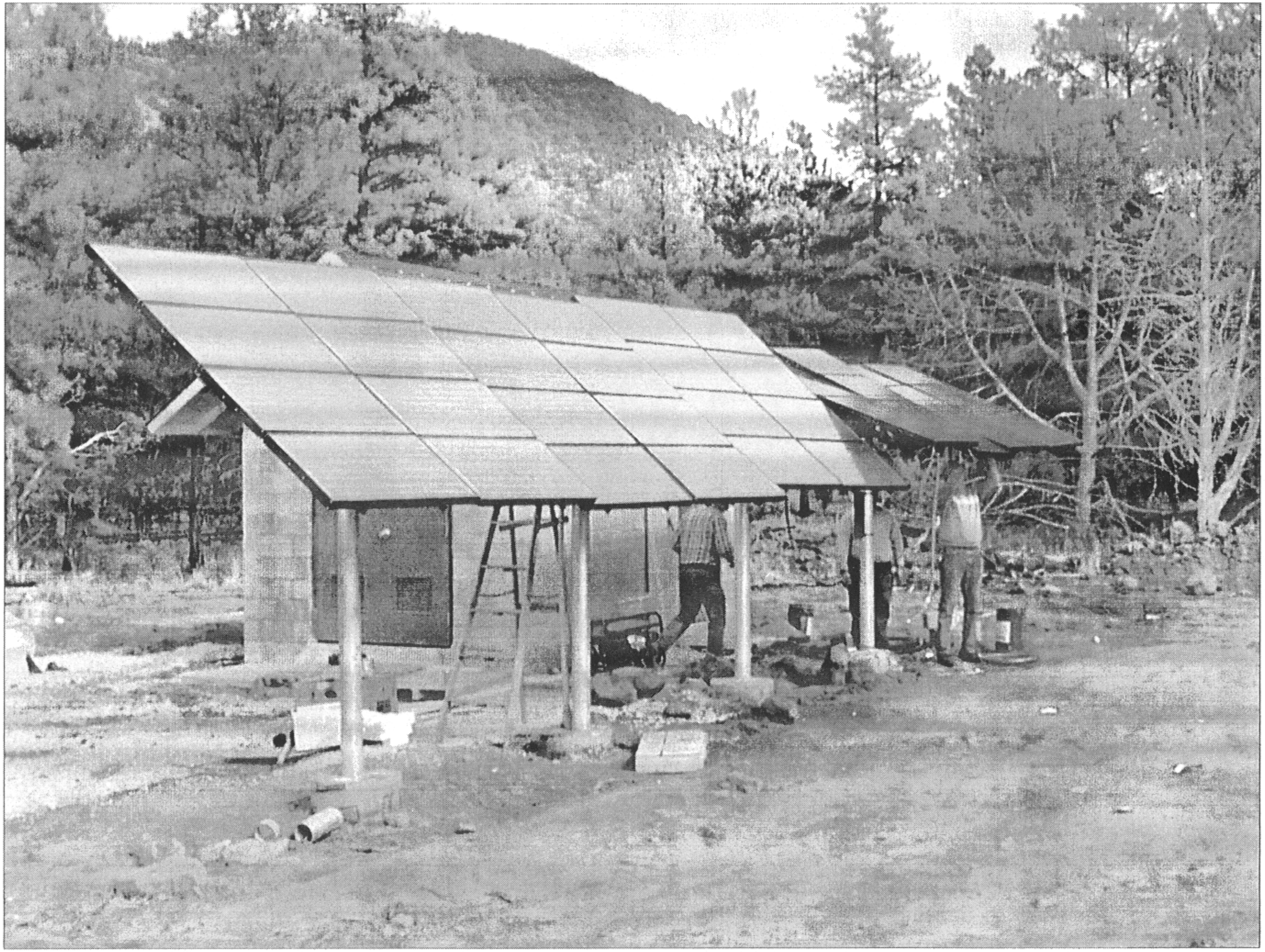
The following table provides a summary of the Photovoltaic equipment required under this contract Additional items and equipment are required to make the system a complete and functional.

Site	Pariette	Chicken	Mt. Trumbull	Mud Flat
# Modules	16	20	40	32
Batteries quantity/model #	8/8G8D	8/8G8D	8/3-90A-23	12/8G8D
Inverter Size (continuous power rating)	4.0 kw	4.0 kw	11 kw (Dual Inverter)	5.5 kw
Output Voltage	120VAC	120VAC	120/240VAC	120VAC
Array mount /tilt	Roof/20°[1]	Roof/64°[1]	pole	pole
Array output cable length	50'	35'	60'	60'
Battery cable length	15'	10'	15'	10'
Delivery Location	Vernal Field Office 170 S. 500 East Vernal, UT 84078	Tok Field Office P.O. Box 309 Tok, Alaska 99780	Arizona Strip Field Office 345 E. Riverside Dr. St. George, UT 84790	Boise Field Office 3948 Development Ave. Boise, ID 83705-5389
Contact	John Wood (435) 781-4400	Kent Davis (907) 883-5121	Ken Moore (435) 628-4491	Bob Stucker (208)384-3300



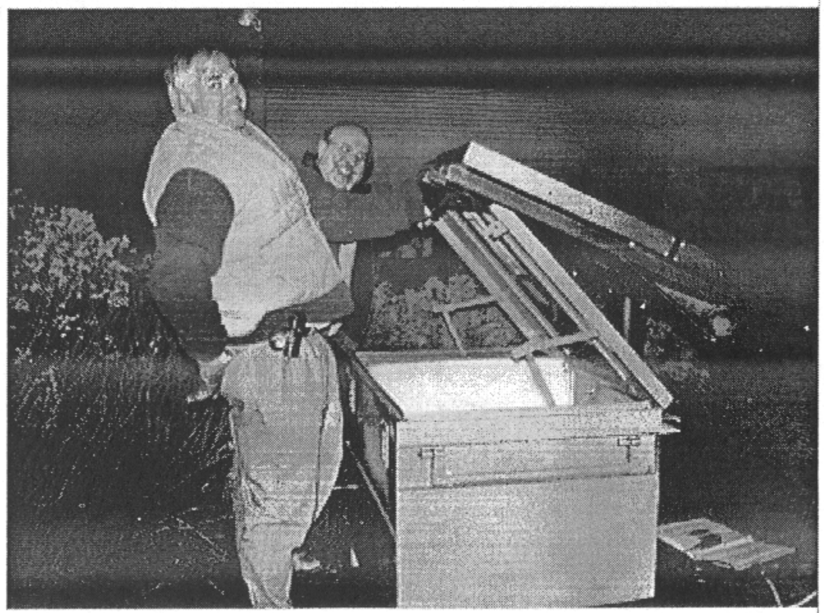
Host hands-on training sessions

Involve users in installation



BLM Lessons Learned

- Wilderness Rangers are not the minimalists that they think they are.
- Loads will grow or shrink, based on the energy available
- Standalone PV will not work with-in 5 miles of a grid power.
- An assessment is not complete without Ribs.



PV Hybrid System Design Alternatives
Needles District
Canyonlands National Park

Andrew L. Rosenthal
Southwest Technology Development Institute
Las Cruces, NM 88003

1998 Photovoltaic Performance and Reliability Workshop

SWTDI

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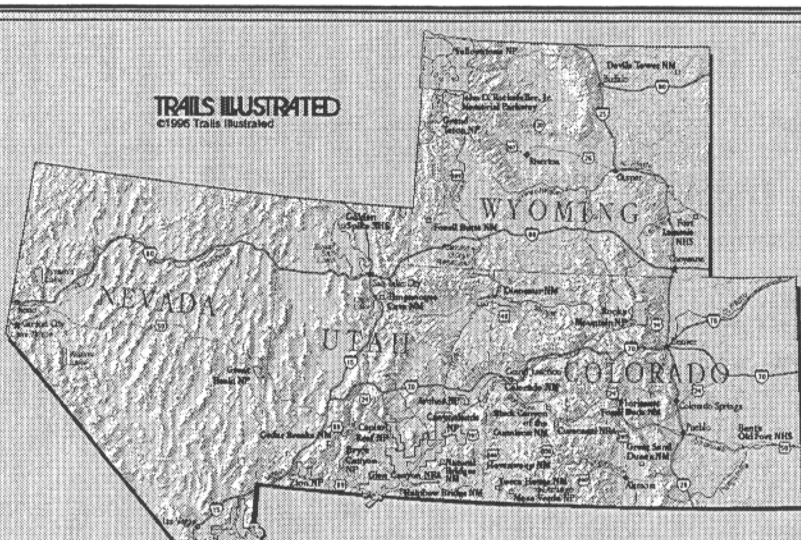

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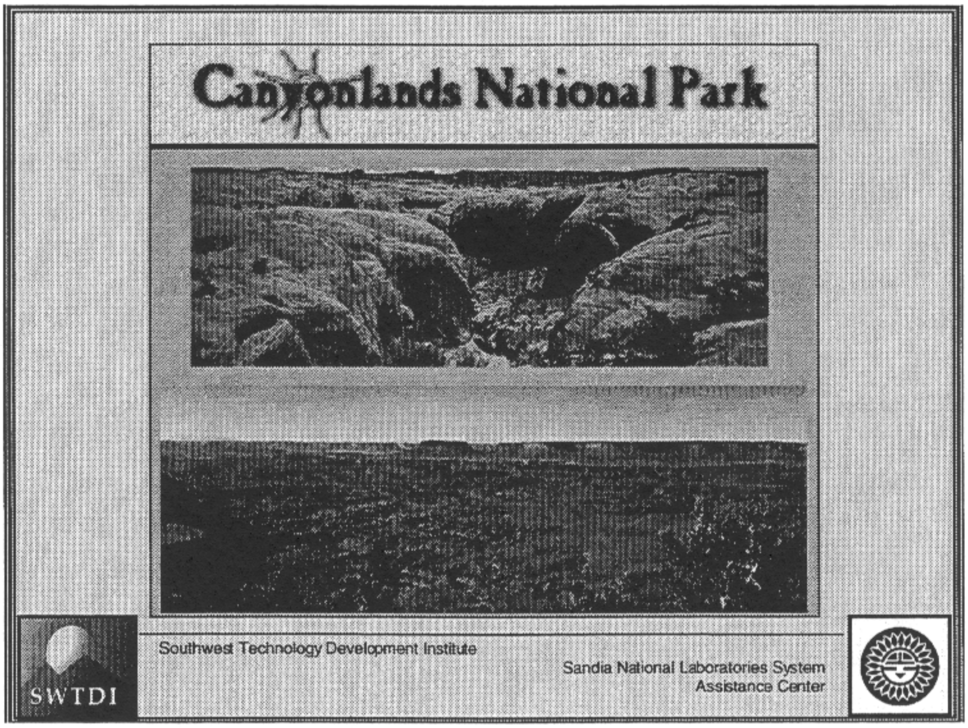

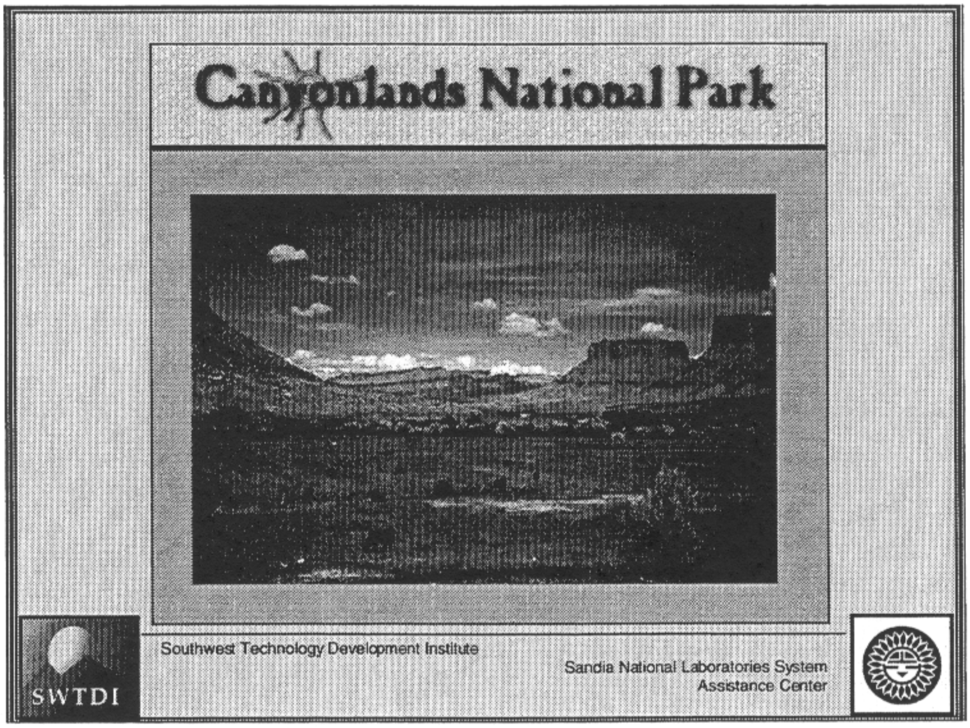

PV Hybrid System Design Alternatives, A. L. Rosenthal

PV Hybrid System Design Needles District

- Located 34 miles from utility grid
- Electricity produced by two 125 kW diesel generators
- Site load approximately 152,000 kWh per year
- Fuel consumption 20,600 gal per year
- Operating cost $45,000 per year ($.30/kWh)

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PV Hybrid System Design Needles District

National Park Service Reasons for Wanting PV

- National Energy Conservation Policy Act (1978), Energy Policy Act (1992), Executive Order 12902 (1994) to reduce fuel consumption, improve energy efficiency and increase investments in renewable energy technologies
- Reduce air quality, noise and visual impacts
- Reduce recurring energy and maintenance costs

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PV Hybrid System Design Needles District

Working Partners

- National Park Service Southeast Utah Group
- State of Utah Department of Natural Resources
  Office of Energy and Resource Planning (OERP)
  National Parks Energy Partnership Program
- Sandia National Laboratories
  Renew the Parks Program
- Southwest Technology Development Institute
  State of Utah Strategic Regional Partnership

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Assistance Center

PV Hybrid System Design Needles District

Work Plan

• Site Evaluation	Q2 1998
• Computer Modeling	Q2 and Q3 1998
• Specification and RFP	Q4 1998
• System Installation	Q2 1999
• Acceptance and Workshop	Q3 1999
• First Year Report	Q4 2000

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PV Hybrid System Design   Needles District

Site Loads

- Visitor Center, Entrance Station, Well, Telephone Service Building
- Generator/Water Treatment Building
- Ranger Office, Maintenance Shop, Flammable Storage Building
- Several Residence Duplexes
- Underground 15kV service (pad mount transformers) to all loads.

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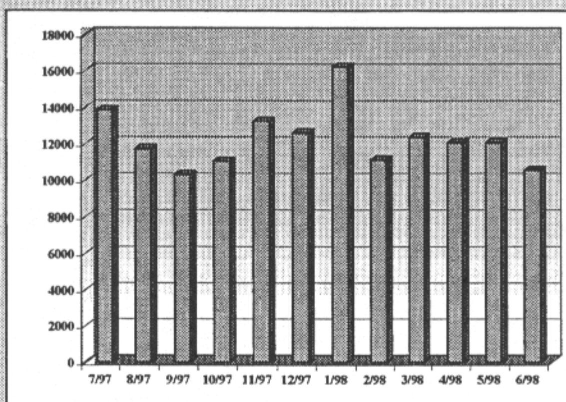
PV Hybrid System Design   Needles District

Total Electrical Load per Month



Note: No strong seasonal trend

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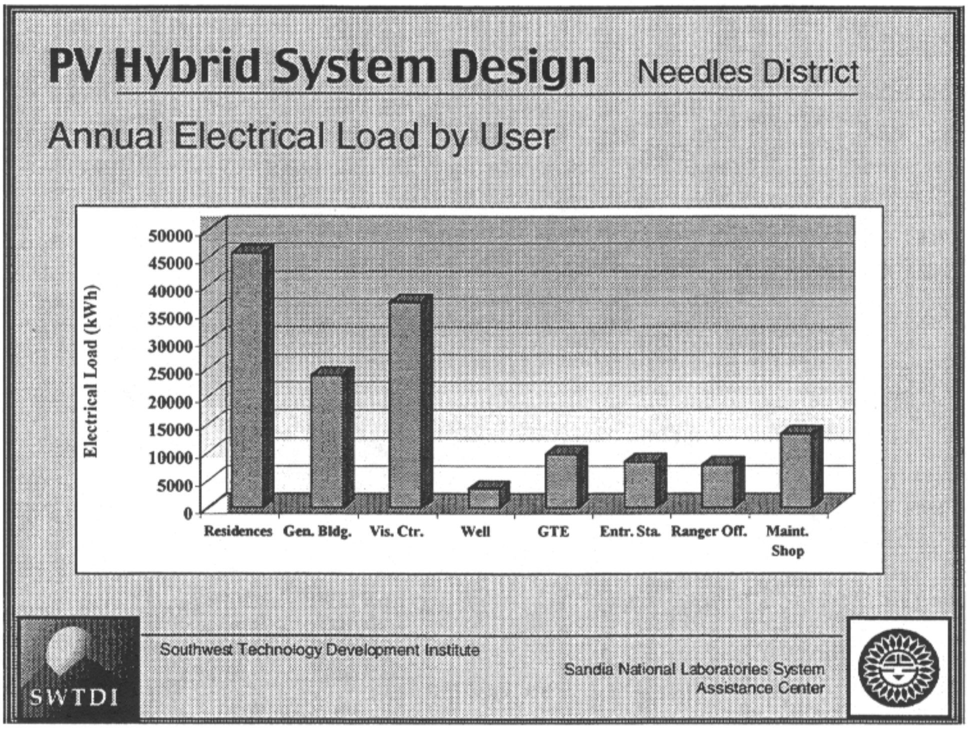
PV Hybrid System Design
Needles District
Annual Electrical Load by User
Electrical Load (kWh)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Residences
Gen. Bldg.
Vis. Ctr.
Well
GTE
Entr. Sta.
Ranger Off.
Maint. Shop
Southwest Technology Development Institute
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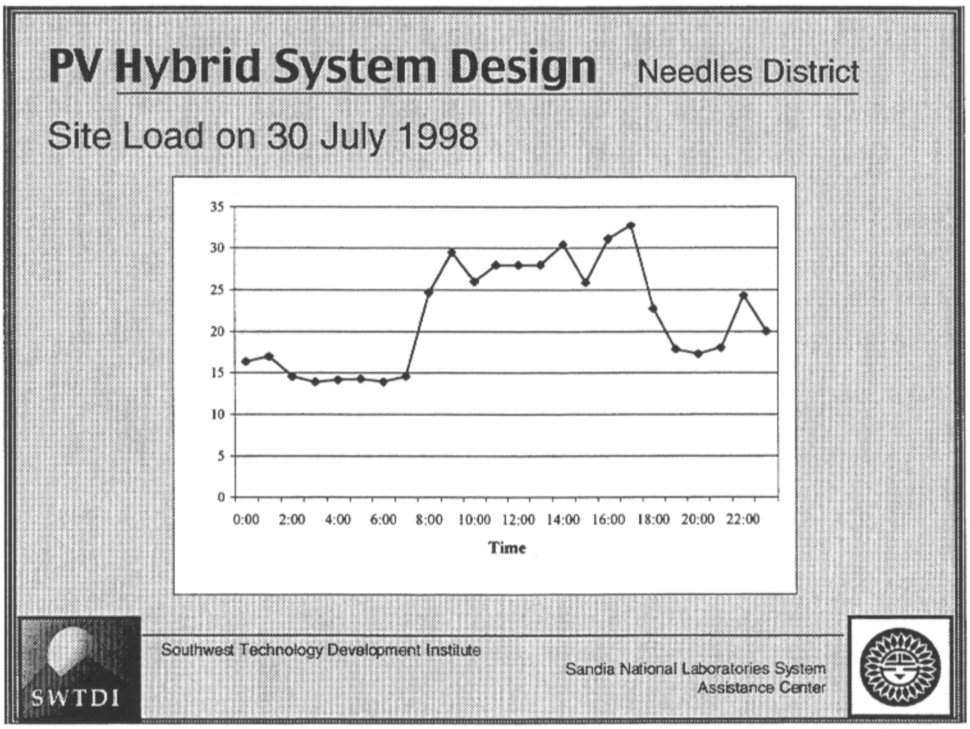
SWTDI


PV Hybrid System Design
Needles District
Site Load on 30 July 1998
35
30
25
20
15
10
5
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time
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PV Hybrid System Design Needles District

Recommended Energy Efficiency Improvements

- Most residential thermal load (heating, cooling, hot water) already propane
- Main step-up transformer is oversized at 300 kVA — replacing by 76 kVA unit will save >20 kWh/day, >7000 kWh/yr.
- Each of the 7 step-down transformers is oversized — replacements will save >5100 kWh/yr.
- Generator building lighting has 20 T12 fixtures — replacement with T8/electronic ballasts will save 1400 kWh/yr.
- Complete retrofit of Visitor Center lighting will save >20 kWh/day, >7000 kWh/yr.
- Total savings: 21,100 kWh/yr (13.8% of the 1997 total load).

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PV Hybrid System Design Needles District

TABLE E-1. Six Power Generation Configurations Presented in this Report

Name	Description
Base Case	The present power system: two 125 kW diesel generators, 7.6 kV distribution system.
Battery-Inverter	The *Base Case* system with the addition of 1000 kWh battery bank and one 50 kVA 3-phase inverter/rectifier.
50 kW PV	The *Battery-Inverter* system with the addition of a 50 kW PV array.
40 kW PV	The *Battery-inverter* system with the addition of a 40 kW PV array.
20 kW PV	The *Battery-Inverter* system with the addition of a 20 kW PV array.
Visitor Center PV	The *Base Case* system with the addition of 800 kWh battery bank and one 30 kVA 3-phase inverter/rectifier (located at the generator building) *plus* one 15 kW single-phase inverter and 15 kW PV array (located at the Visitor Center).

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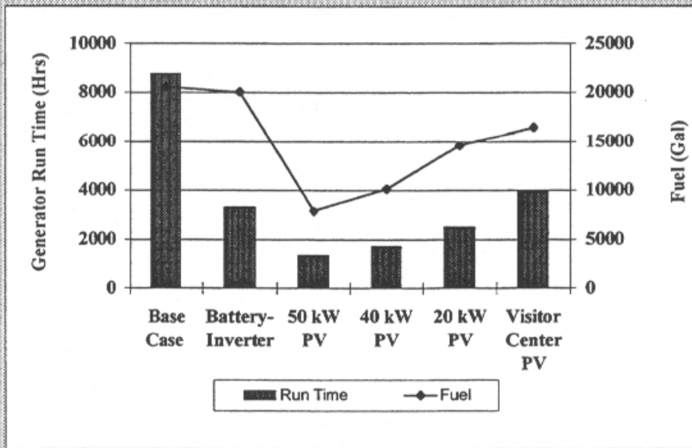
Sandia National Laboratories System Assistance Center

PV Hybrid System Design Needles District

Figure 3-1. Generator run-time and fuel-use for the six power systems



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PV Hybrid System Design Needles District

Table 3-3. Six Power Generation Configurations: Run-Time, Fuel-Use, Maintenance and Replacement Costs

	Base Case	*Battery-Inverter*	*50 kW PV*	*40 kW PV*	*20 kW PV*	*Visitor Center PV*
Generator Run-Time (Hrs)	8760	3296	1139	1720	2480	3920
Generator Fuel-Use (Gallons/$)	20,600/ $22,248	20,038 $21,641	7,882/ $8,513	10,100/ $10,908	14,533/ $15,696	16,416/ $17,729
Recurring Annual Maintenance ($)	$10,918	$4,650	$3,450	$3,600	$4,050	$4,950
Non-recurring Maintenance ($)	$15,262 every 3.5 yrs (rebuild engines)	$15,262 every 9 yrs (rebuild engines)	$0	$0	$15,262 in year 12 (rebuild engines)	$15,262 every 8 yrs
Battery Replacement ($)	$0	$100k (replacement in year 10)	$100k (replacement in year 10)	$100k (replacement in year 10)	$100k (replacement in year 10)	$80k (replacement in year 10)
Generator Replacement ($)	$125k (in year 12)	$0	$0	$0	$0	$0

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Sandia National Laboratories System Assistance Center

PV Hybrid System Design Alternatives, A. L. Rosenthal

PV Hybrid System Design Needles District

Table E-2. Six Power Generation Configurations: Performance Characteristics, Pros and Cons

Name	*Annual Generator Run-Time (hours)*	*Annual Generator Fuel-Use (gallons)*	*Purchase Price ($)*	*20-year Life-Cycle Cost (LCC)*	*Pros (compared) with the base case)*	*Cons (compared) with the base case)*
Base Case	8760	20,600	-	$612,000	-	-
Battery Inverter	3296	20,038	$203,000	$668,000	Low LCC, 38% gen run-time and maintenance	No fuel
50 kW PV	1339	7882	$528,000	$766,000	15% gen run-time and maintenance, 38% fuel-use	High initial cost, high LCC
40 kW PV	1720	10,100	$463,000	$738,000	20% gen run-time and maintenance, 49% fuel-use	High initial cost, high LCC
20 kW PV	2480	14,533	$333,000	$694,000	20% gen run-time and maintenance, 71% fuel-use	Med initial cost, med LCC
Visitor Center PV	3920	16,416	$278,000	$677,000	Low LCC 45% gen run-time and maintenance	Only moderate fuel savings

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PV Hybrid System Design Needles District

Table 3-5. Six Power Generation Configurations: Emissions and Revised Life-Cycle Costs

	Base Case	*Battery-Inverter*	*50 kW PV*	*40 kW PV*	*20 kW PV*	*Visitor Center PV*
Emission						
CO2 tons/yr $/yr	230 $3,222	224 $3,134	88 $1,233	113 $1,580	162 $2,273	184 $2,567
SO2 lbs/yr $/yr	691 $519	672 $504	264 $198	339 $254	488 $366	551 $413
NOx lbs/yr $/yr	6,692 $22,754	6,510 $22,133	2,560 $10,138	3,280 $11,153	4,721 $16,052	6,510 $22,133
Revised Net Present Value	$968,813	$1,015,095	$902,784	$913,310	$945,841	$1,015,595

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PV Hybrid System Design — Needles District

Annual Cost to Run Diesel generators at the Needles

- Fuel = $22,252
- Regular Maint/Parts = $10,918
- Overhaul (every 3 yrs) = $15,262
- Total cost is $3,194/mo of which 58% is fuel cost.

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PV Hybrid System Design — Needles District

Key LCC Difference between Generators and PV Hybrids

- Generator System: Purchase price comprises 10 - 15% of total cost of ownership
- PV Hybrid: Purchase price comprises 70 - 75% of total cost of ownership
- PV Hybrid Initial costs scale linearly with system size; Generator operating costs do not.

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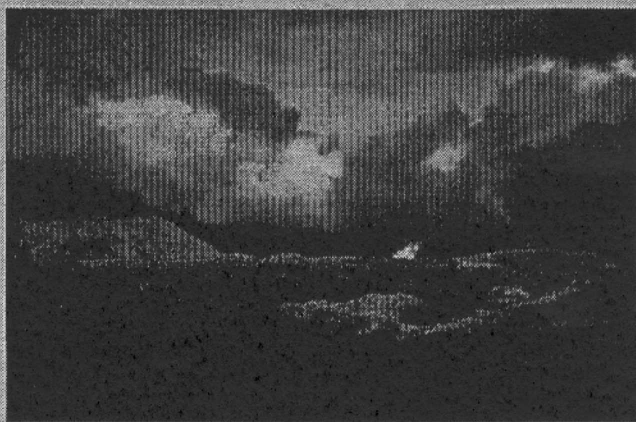
Canyonlands National Park



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PV Hybrid System Design Needles District

Conclusions

- **Excluding emissions penalties, the existing diesel generators provide the cheapest energy option.**
- **Including emissions penalties, 50 kW PV Hybrid provides lower 20-year LCC (payback in year 17).**
- **National Park service will make its decisions based on these findings, cost share commitments by partners and their FY99 budget.**

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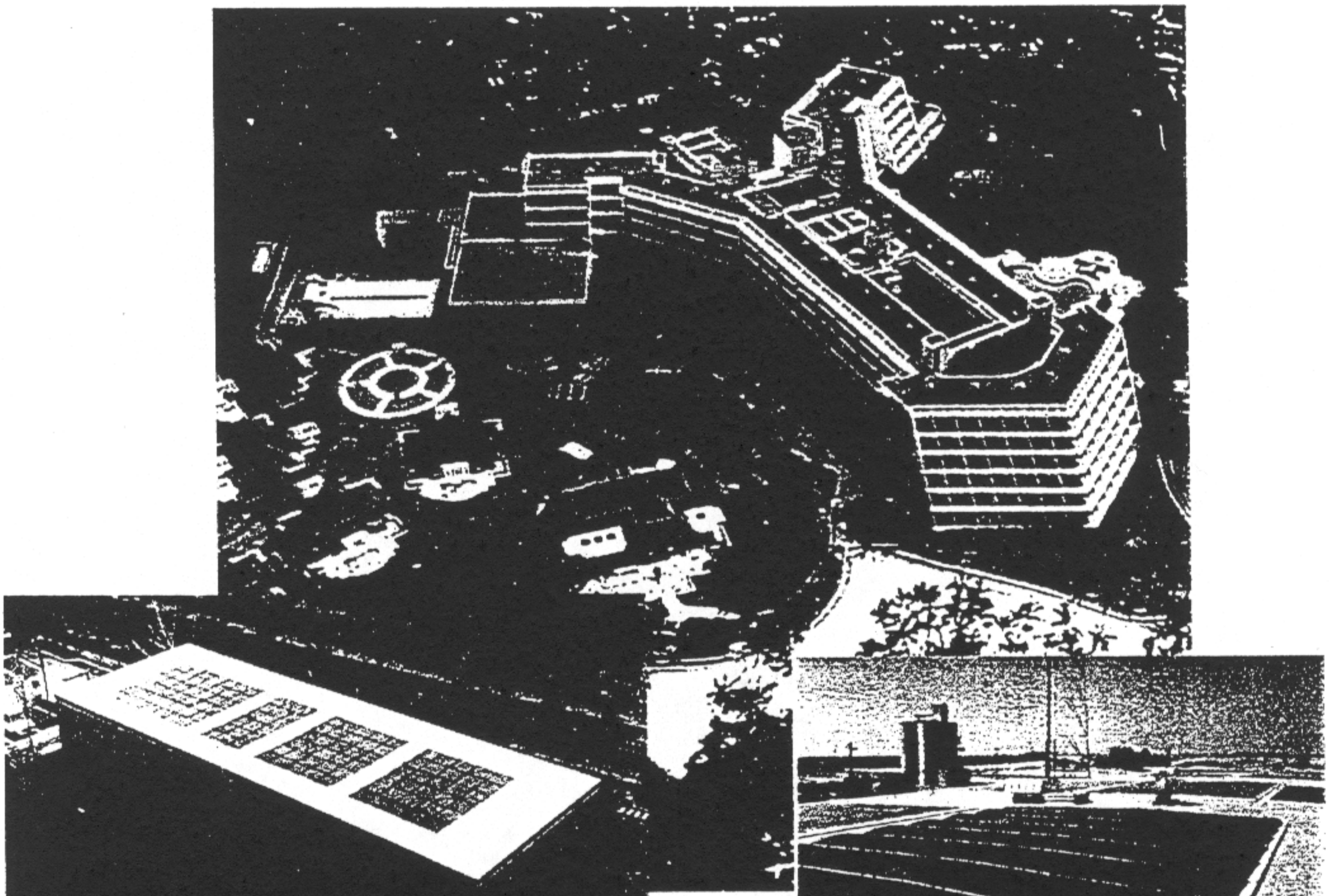
PV Hybrid System Design Alternatives, A. L. Rosenthal

PowerLight
Corporation

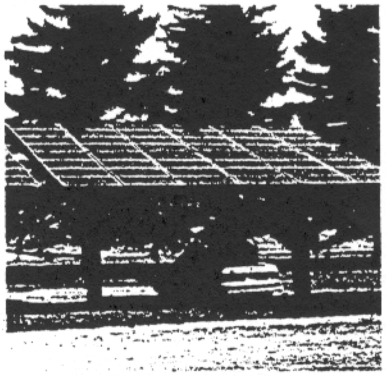
Building-Integrated Photovoltaic Systems

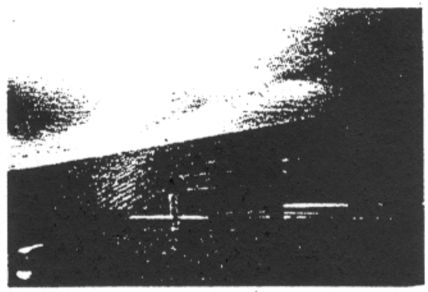


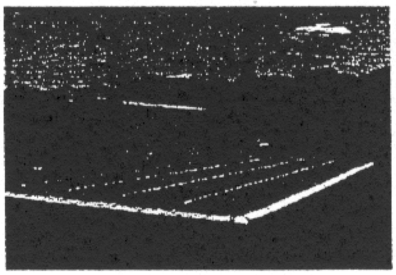
PowerLight Products

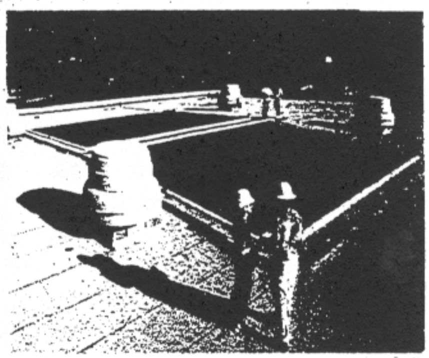
Building-Integrated PV:

- PV Glazing
- Carports
- PowerGuard• Sloped PV Roofing Tile
- PowerGuard• Flat PV Roofing Tile



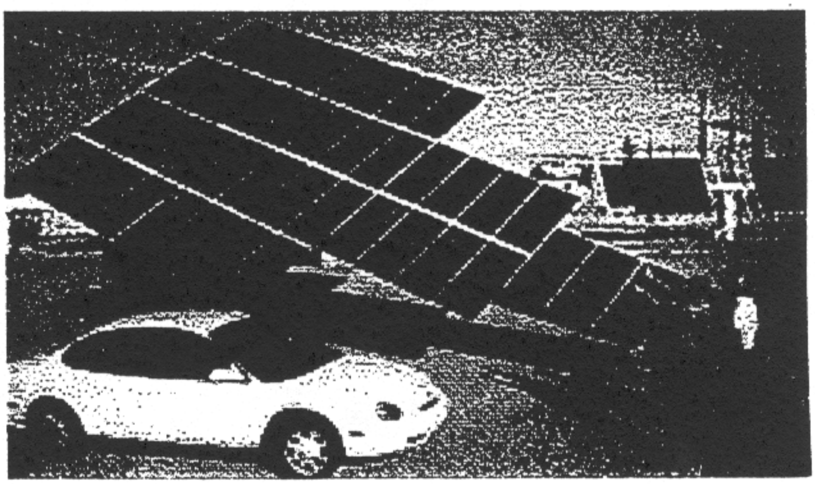






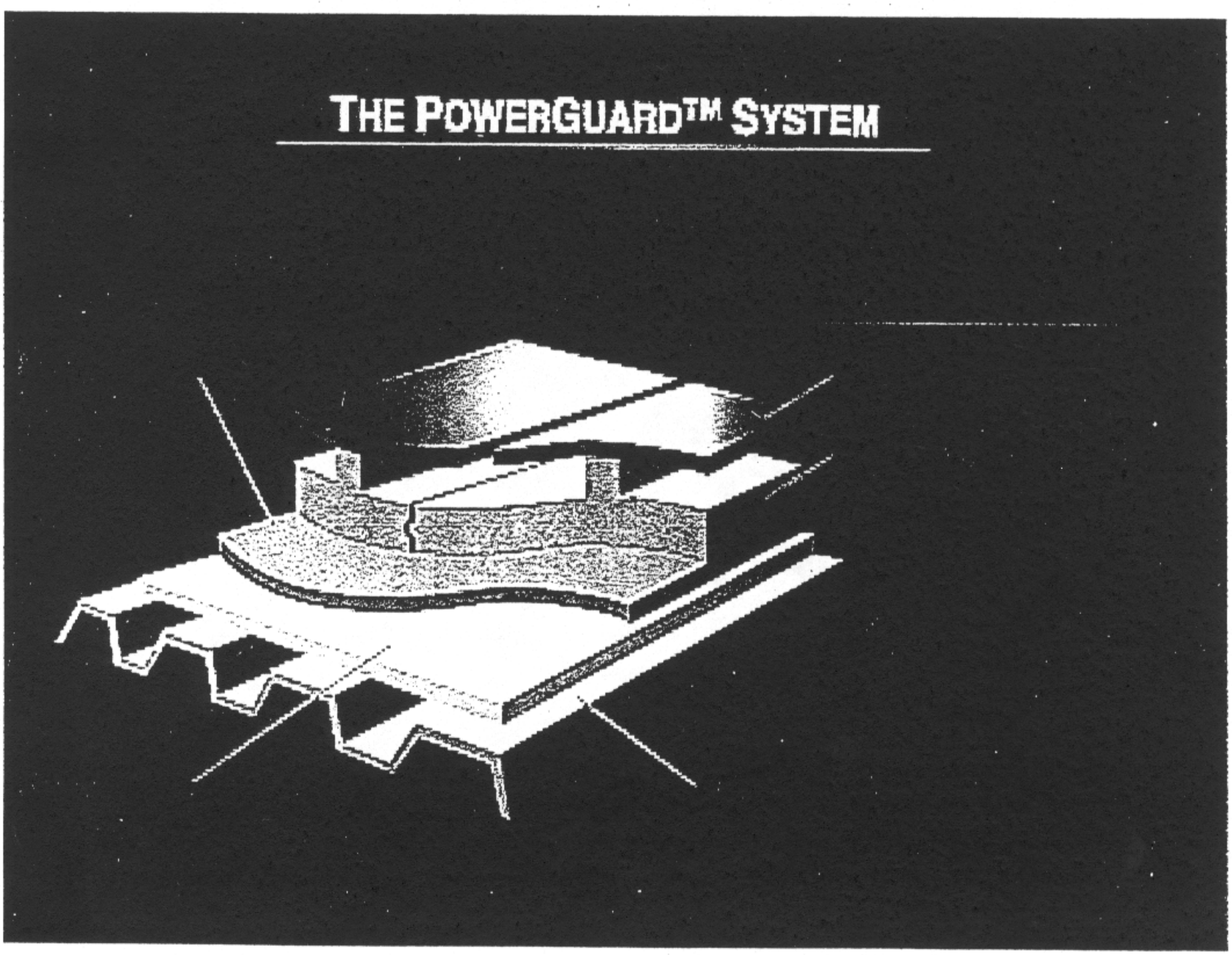
Other PV Products:

- PolarTracker• -Ground mounted tracking system



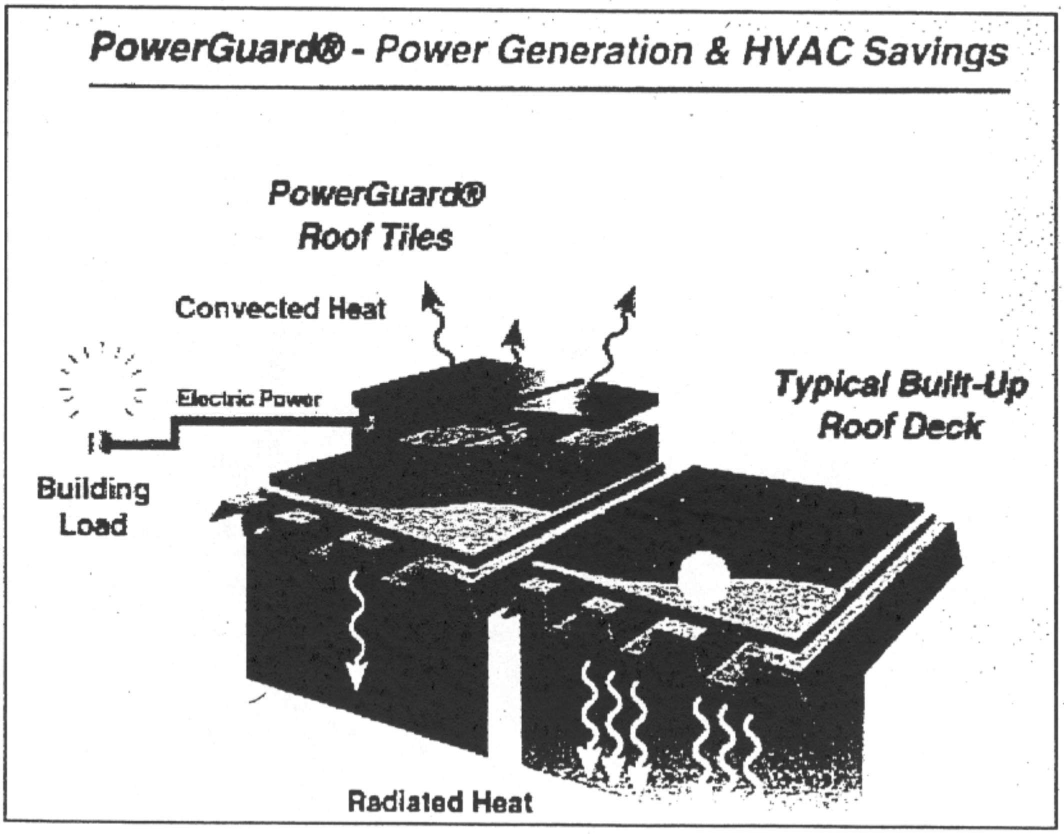
Product Development Criteria

- Value Added to PV
- Established Market
- Industry Standard

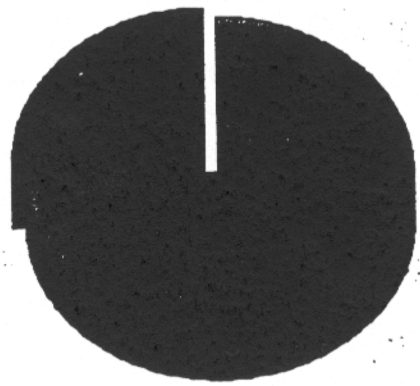


PowerGuard Adds Value to PV:

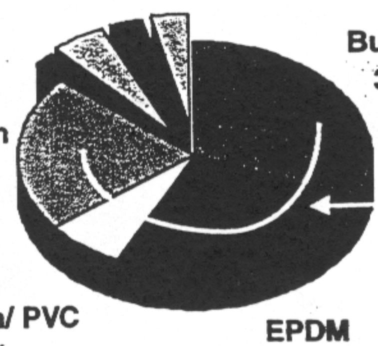
- Additional roof insulation-HVAC savings
- Extend life of existing roof up to 30 years
- Proven Electrical Performance



PowerGuard Taps Existing Market



Commercial Roofing Market $ 16 Billion / year

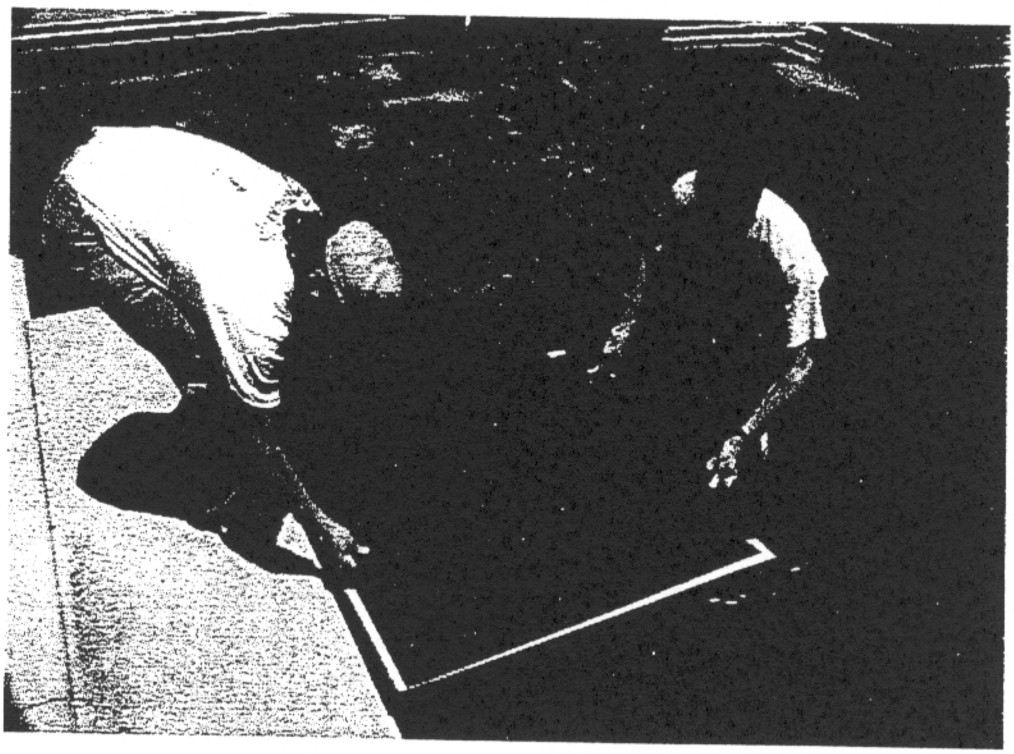


Source: National Roofing Contractors Association

PowerGuard Conforms to Roof Industry Standards

Standard Roofing Tile Characteristics:

- Looselaid on roof membrane - no roof penetrations
- Lightweight (4 lb/sf)
- Proven reliability
- UL approved product

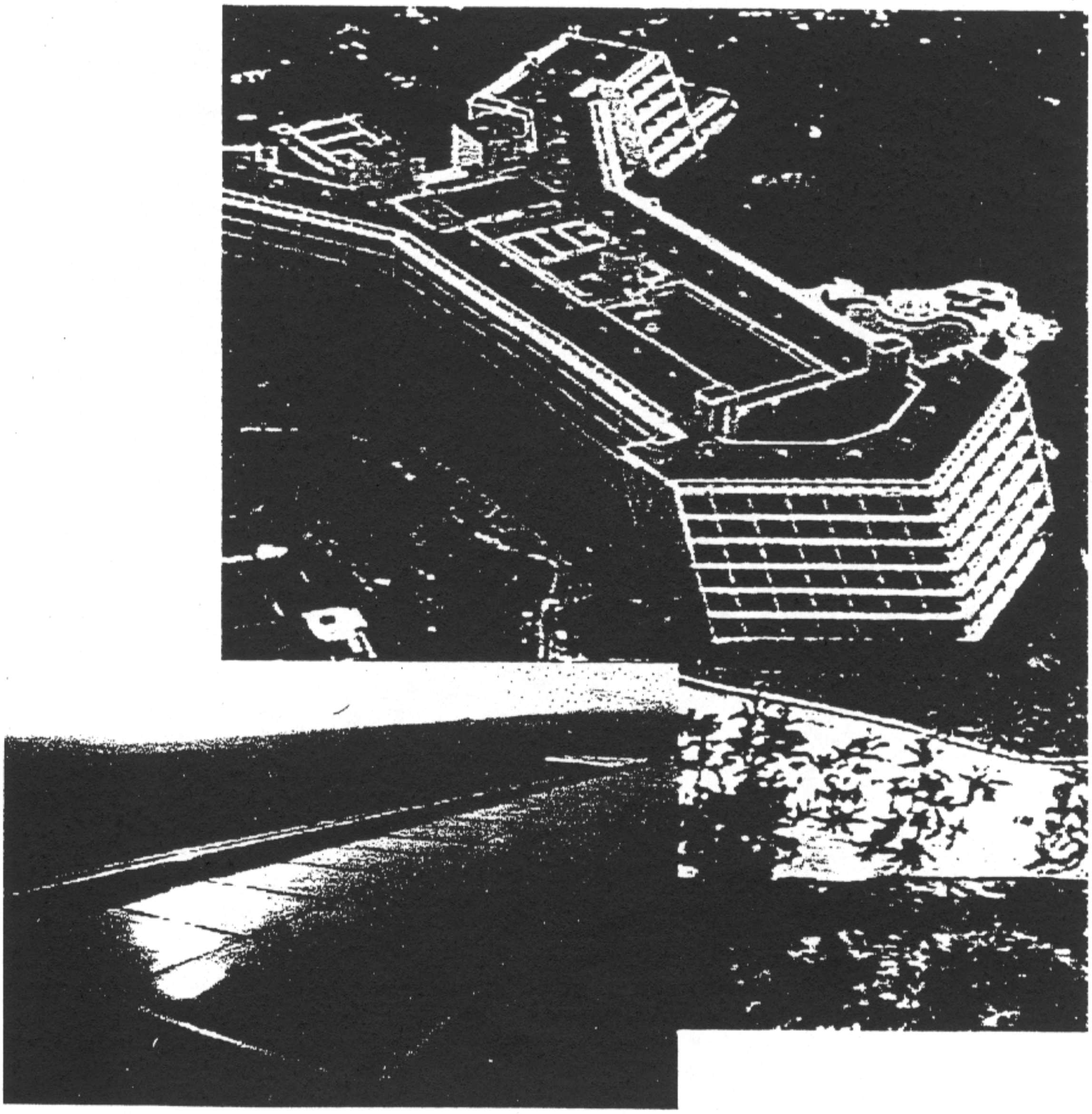


Building-Integrated Photovoltaic Systems

PowerLight Corporation

Case Study: 75 kW PowerGuard System

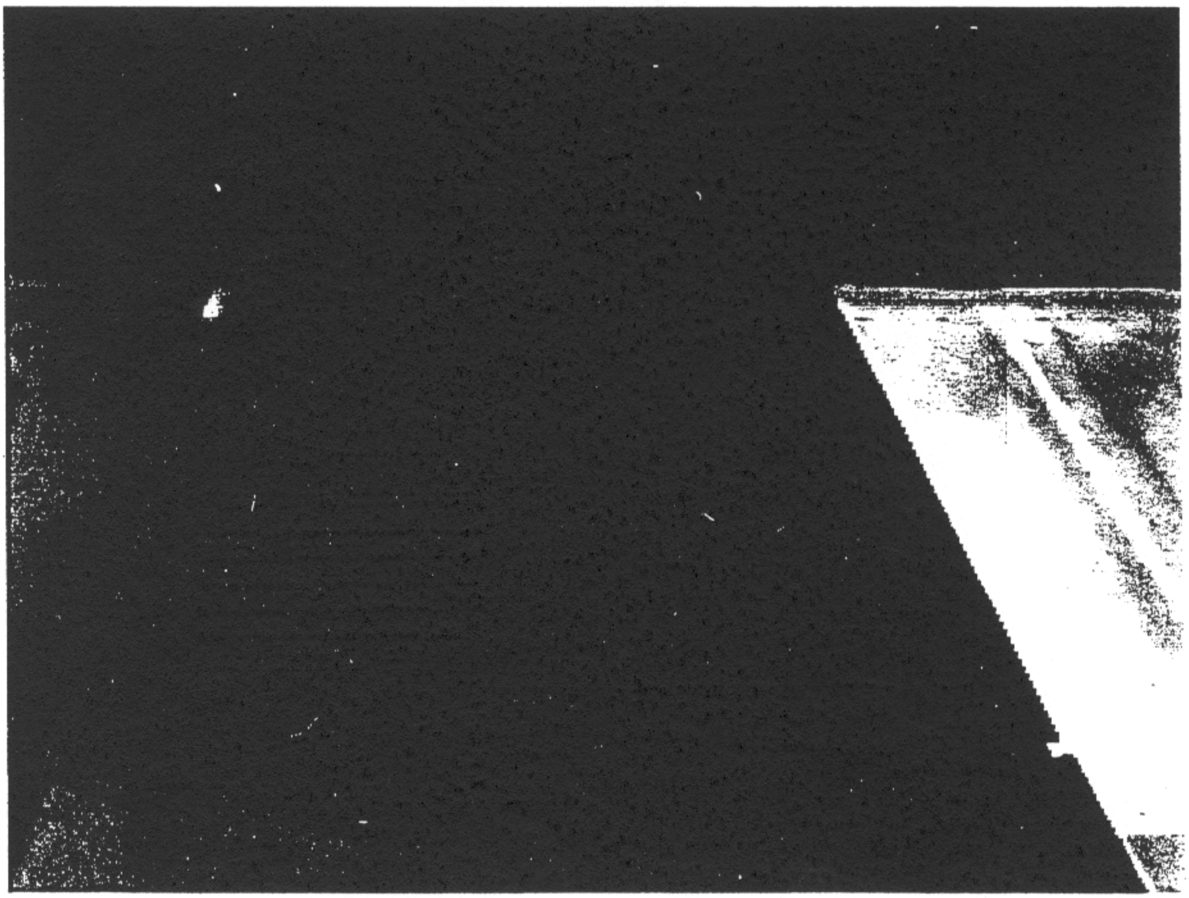
Owner: Mauna Lani Bay Resort Hotel
Site: Kohala Coast, HI



Case Study: 75 kW PowerGuard System

PowerGuard Thermal Performance:

- Roof temperature reduced from 80° to 40° C

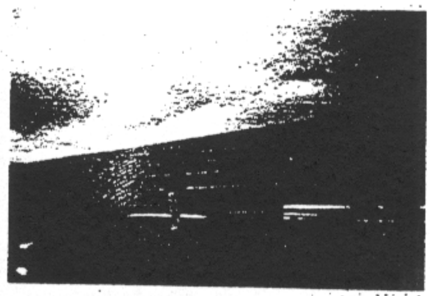


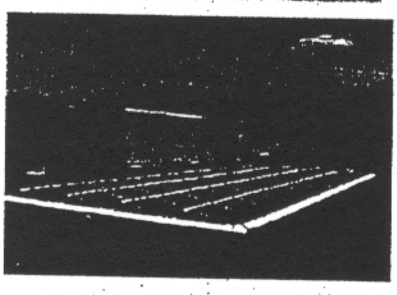
PowerLight Products Meet Development Criteria

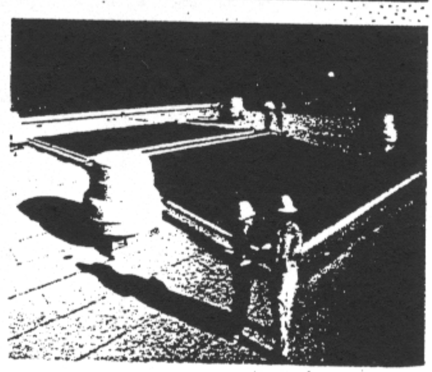
- Value Added to PV
- Established Market
- Industry Standard

Building-Integrated PV:

- PV Glazing
- PowerShade Carports
- PowerGuard Sloped PV Roofing Tile
- PowerGuard Flat PV Roofing Tile

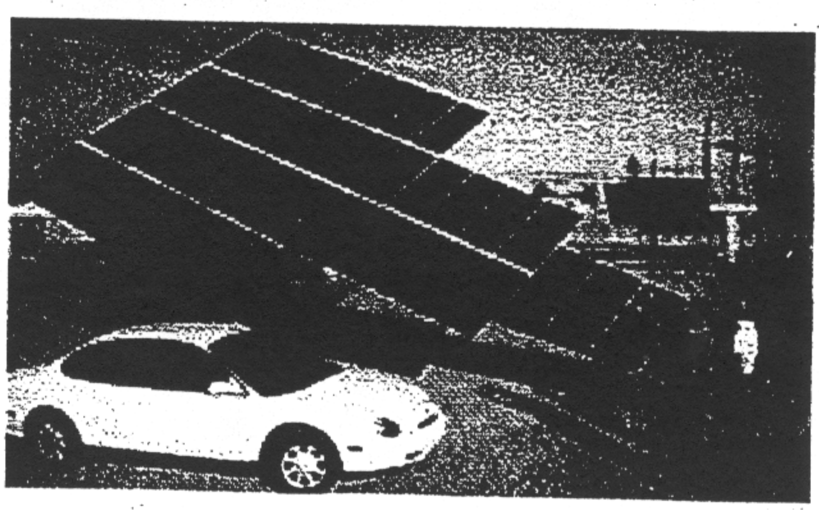






Other PV Products:

- PolarTracker -Ground Mounted Tracking system



PV BATTERY STORAGE

STATUS REPORT AND LESSONS LEARNED

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ABSTRACT

Over the last eight years Sandia National Labs and the Florida Solar Energy Center have conducted numerous laboratory and field tests on both vented (flooded) lead-antimony and valve regulated lead-acid (VRLA) batteries commonly used in PV systems. The objectives of this work have been to better understand and characterize how these popular battery types operate in PV systems, and to develop information on how to optimize performance and cycle-life in these applications. This presentation provides an overview of this work and the principle findings.

As expected, our test results indicate that battery performance in PV systems is highly dependent on the type of battery used, the charge regulation methods and operating environment, the sizes of the PV array and load, and component reliability. In general, these variables and their interdependence have made it very difficult to reasonably estimate battery cycle-life performance in PV systems. However, our evaluations have shown that there are clear relationships between certain system design variables and their effect on battery performance and lifetime.

Information developed from this work has included classification of PV battery types, their advantages and disadvantages, and their recommended charge regulation methods using different control algorithms. Field experience has shown certain failure mechanisms for specific battery types, and comparisons of battery capacity and electrolyte loss over time for certain control strategies and setpoint values. As a result of these evaluations, relationships between PV system design parameters and battery health are becoming better understood. These system design parameters include the PV to load energy ratio, battery depth of discharge and the amount of overcharge received. A significant part of this work has involved interactions with PV system integrators and battery and controller manufacturers, which has resulted in a new and/or improved charge controllers, better battery specifications and a better understanding of system design requirements.

Further details of this work are contained the reference documents listed below:

1. S. Harrington and J. Dunlop; **Battery Charge Controller Characteristics in Photovoltaic Systems**, 7th Annual Battery Conference on Advances in Applications, January 1992.
2. J. R. Woodworth, et. al., "**Evaluation Of The Batteries And Charge Controllers In Small Stand-Alone Photovoltaic Systems**", IEEE PVSC, Dec. 1994.
3. S.R. Harrington, and T. D. Hund, "**Photovoltaic Lighting System Performance**", IEEE PVSC, May 1996.
4. J. P. Dunlop, "**Venice Photovoltaic Lighting Systems Evaluation Report**", FSEC field evaluation report, Jan. 10, 1997.
5. J. P. Dunlop, "**Photocomm 'Olympic' PV Lighting Systems**", FSEC field evaluation report, Feb. 1997.
6. J. P. Dunlop, "**Photovoltaic Lighting Systems for Brevard Community College's COMET Walkway**", FSEC field evaluation report, Sept. 25, 1997.
7. J. P. Dunlop, **Batteries and Charge Control in Stand-Alone Photovoltaic Systems: Fundamentals and Application**", Florida Solar Energy Center, January 1997.

Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000. The Florida Solar Energy Center is a research institute of the University of Central Florida, and conducts contract work for Sandia under the DOE PV program.

FSEC

PV Battery Storage

A Status Report and Lessons Learned

Sandia National Laboratories

Funded By The DOE PV BOS Program
Work conducted by
Sandia National Laboratories'
Photovoltaic System Applications Dept. and
The Florida Solar Energy Center (FSEC)

Tom Hund, Marlene Brown, and Jim Dunlop (FSEC)
Nov. 4, 1998

PVRC98.ppt 1

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Introduction

Sandia National Laboratories

- **Over eight years of experience**
- **Testing vented and valve regulated lead-acid batteries**
- **Test results show that battery cycle-life is dependent on**
  - **charge controller setpoints for specific battery**
  - **component reliability**
  - **battery technology**
  - **system design**

PVRC98.ppt 2

PV System Field Evaluations

FSEC — Sandia National Laboratories

- Sandia/FSEC Battery and Charge Controller Test Bed, 28 systems, 1990- 94
- Sandia/Tramway PV Lighting Systems, 21 systems, 1992- 96
- FSEC/Venice PV Lighting Systems, 10 systems, 1996- 97
- FSEC/MLK Jr. Nat'l Historical Site, 42 systems, 1996- 98
- FSEC/BCC Comet Walkway Lighting Systems, 15 systems, 1997- 98

PVRC98.ppt 3

Lab and Field Evaluations Objectives

FSEC — Sandia National Laboratories

- Phase 1
  - Identify what's presently available in charge controllers (1990)
  - Do they work? If not why? Evaluated seven different charge controllers
    - Evaluate CV and on/off
    - Evaluate effects of Vr, Vrr, and LVD
    - Evaluate battery maintenance and cycle-life performance
    - Evaluate PV array to load ratio

PVRC98.ppt 4

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Lab and Field Evaluations
Objectives

Sandia National Laboratories

- **Phase 2**
  - Evaluate new higher setpoints
  - Evaluate new array to load ratio
  - Evaluate maintenance
  - Evaluate battery performance

PVRC98.ppt 5

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Lab and Field Evaluations
Objectives

Sandia National Laboratories

- **Phase 3**
  - Use test results from Phase 1 and 2 in fielded stand-alone PV systems
  - Evaluate battery performance
  - Evaluate temperature compensation
  - Evaluate hardware reliability
  - Evaluate maintenance
  - Evaluate Hydrocaps®
  - Evaluate Zomeworks Cool Cell™
  - Evaluate battery boost charge

PVRC98.ppt 6

Sandia/FSEC Battery and Charge Controller Test Bed 28 Systems, 1990 - 94

FSEC — Sandia National Laboratories

- **Test Results**
  - Factory recommended Vr/Vrr ranged from 14.25/12.9 on/off to 14.54/13.45 volts on/off and 14.4 volts constant voltage
  - Battery SOC is very dependent on Vrr A Vrr of 13.4 or less results in a SOC of 70% or less.
  - A 14.1 Vrr to 14.4 CV resulted in a SOC of 90% or more

PVRC98.ppt 7

Sandia/FSEC Battery and Charge Controller Test Bed 28 Systems, 1990 - 94

FSEC — Sandia National Laboratories

- Water loss on new batteries increased from
  ~123 ml/month at 13.4/14.4 on/off (16 months)
  ~185 ml/month at 14.1/14.5 PWM (10 months)
  ~191 ml/month at 14.4 CV (10 months)
  ~246 ml/month at 13.8/14.8 on/off (8 months)
  ~316 ml/month at 13.85/15.0 on/off (6 months)
  (Trojan T-105 battery (12 volts)requires about 2000 ml water when dry)
- LVD's over 11.4 volts improved average SOC and reduced load availability

PVRC98.ppt 8

Sandia/FSEC Battery and Charge Controller Test Bed 28 Systems, 1990 - 94

- No LVD's resulted in excessive discharges
- To achieve manufacturers rated battery cycle-life required recharging the battery to a high SOC as often as possible.
- Min PV regulation voltage for vented batteries needs to be about 14.4 CV and 14.7/13.7 on/off

PVRC98.ppt 9

Sandia/FSEC Battery and Charge Controller Test Bed 28 Systems, 1990 - 94

- A minimum average monthly array current to load current ratio of about 1.3 was required for good system/battery performance
- External temperature compensation is recommended because of internal heating from the charge controller and temperature differences in battery enclosure in winter

PVRC98.ppt 10

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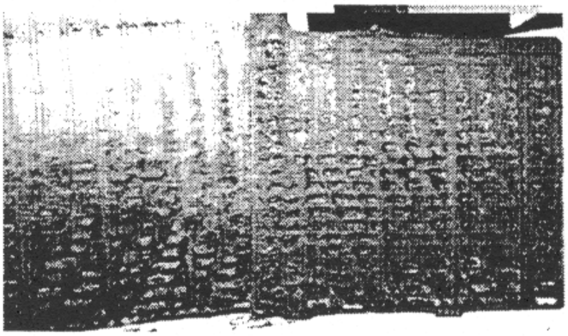
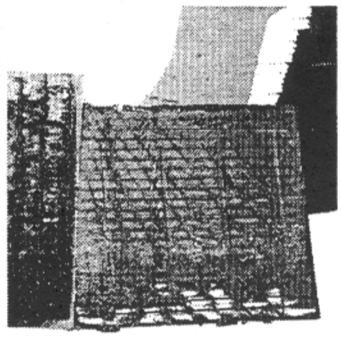
Sandia/FSEC Battery and Charge Controller Test Bed Premature Capacity Loss

Sandia National Laboratories





Gas Pockets
On Negative Plate

Electrolyte Stratification
Negative Grid Corrosion

PVRC98.ppt 11

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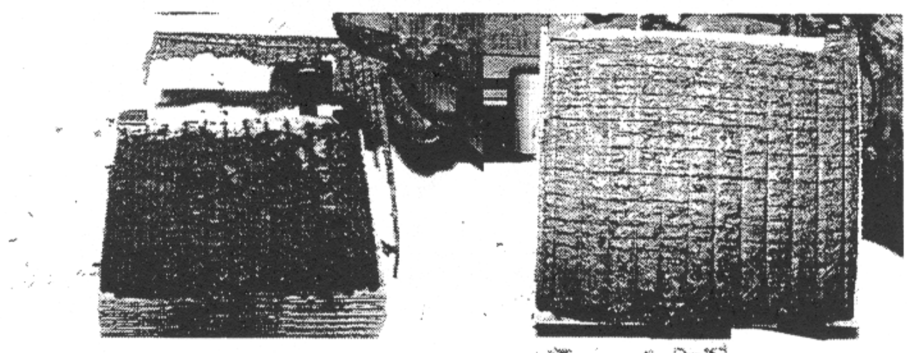
Sandia/FSEC Battery and Charge Controller Test Bed Normal Wear Out

Sandia National Laboratories



Grid Corrosion
On Positive Plate

Grid Growth
On Positive Plate

PVRC98.ppt 12

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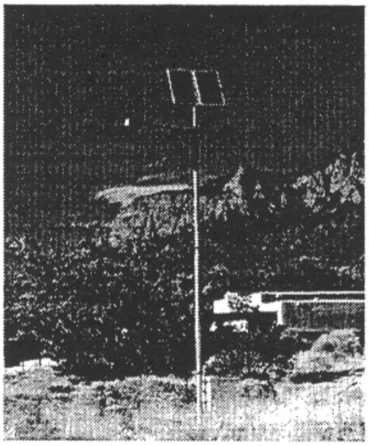
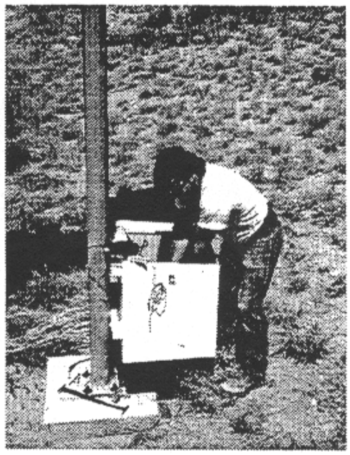
Tramway Lighting Systems
Albuq., 21 LPS 36 W Lights

Sandia National Laboratories





PVRC98.ppt 13

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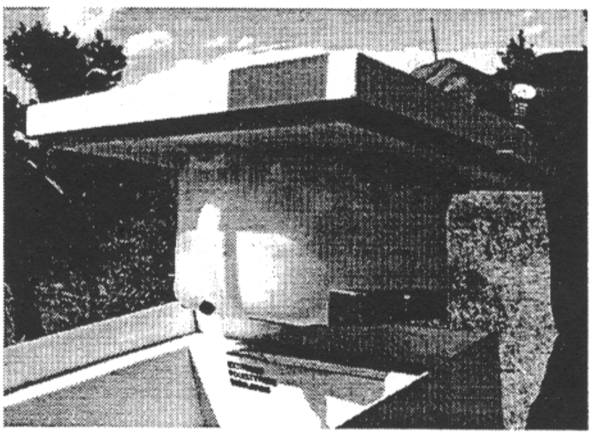
Tramway Lighting Systems
Battery Box, Cool Cell™

Sandia National Laboratories



PVRC98.ppt 14

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Tramway Lighting Systems Results

Sandia National Laboratories

- Both on/off and CV charge controllers maintained adequate SOC with 14.7/13.7 and 14.4 volt setpoints with minimum array to load ratio = 1.27 (PVCAD)
- The vented batteries after 2.5-years were operating at 68 to 95% of their original capacity

PVRC98.ppt 15

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Tramway Lighting Systems Results

Sandia National Laboratories

- After 4.5-years the gel VRLA battery was at end of life (Vr = 14.1 cv, 14.2/13.7 on/off) JCI recommends a 14.4 volt Vr
- Boost charging batteries before installation added 38% to the battery capacity from initial as-received capacity

PVRC98.ppt 16

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Tramway Lighting Systems Results

Sandia National Laboratories

- **Hydrocaps®** (Added cost $36- good cost to benefit - not recommended for use with equalization)
  - reduce water consumption by about 50%
  - inspection intervals were 6-months watering at 18-months
  - Some Hydrocaps "wetted" and needed to be baked out at 100ºC (They get hot when working)
- **Cool Cell™ battery box**
  - Leveled battery temperature by 10 to 15ºC, (works only with cool nights warm days)

PVRC98.ppt 17

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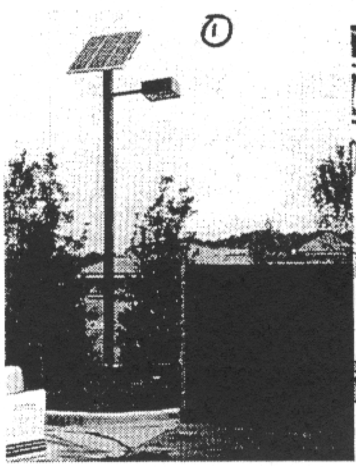
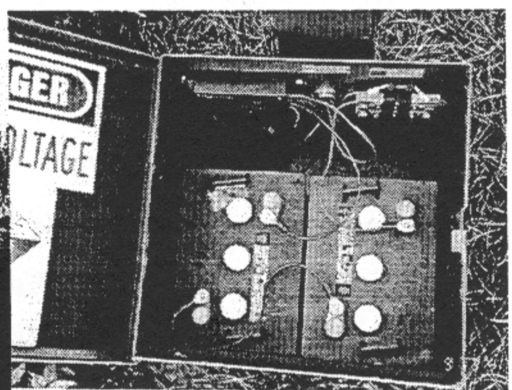
Wendys - Atlanta, GA
2 x 24W Compact Fluorescent

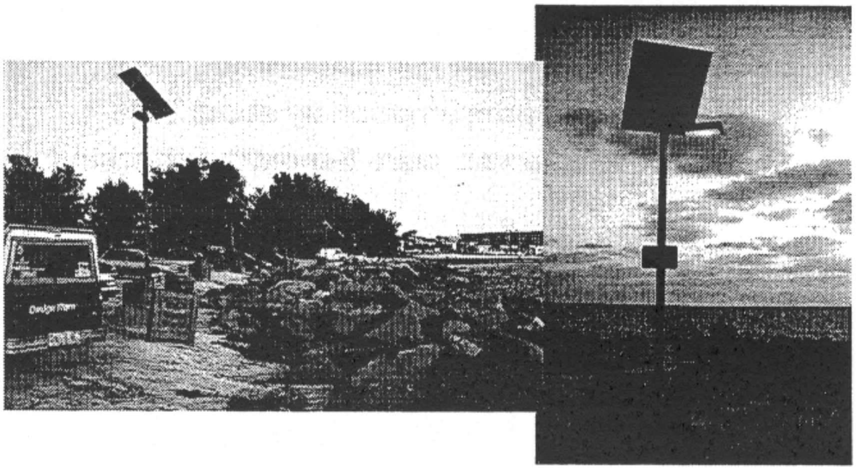
Sandia National Laboratories





PVRC98.ppt 18

Venice, FL - Jetty Park
10 LPS Lights



PVRC98.ppt 19

Venice, FL - Jetty Park
Results

- Trojan RE-10X (SP-125) extra electrolyte batteries maintained over 90% of their original capacity after 1-year
- Average battery temperatures exceeded 30ºC and maximum temperatures exceeded 40ºC

PVRC98.ppt 20

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Venice, FL - Jetty Park Results

Sandia National Laboratories

- Water consumption with Hydrocaps® was about 1/3 - 1200 ml/year Vs 3400 ml without Hydrocaps®
- The battery contains about 3750 ml reserve electrolyte Vs 2000 ml or 47% less for a Trojan T-105 battery
- With the Trojan RE-10X battery and Hydrocaps® water additions would be required about every 2-years for the specified setpoints

PVRC98.ppt 21

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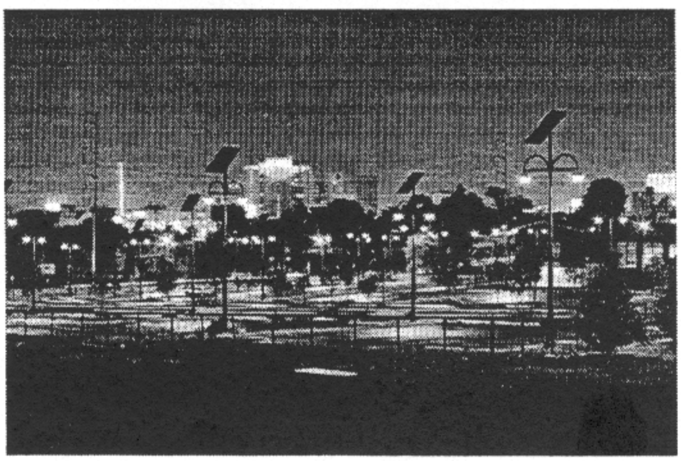
MLK Jr. Nat'l Historical Site 42 Systems, Fluorescent 2 x 36 W

Sandia National Laboratories



PVRC98.ppt 22

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MLK Jr. Nat'l Historical Site Control and Battery Box

Sandia National Laboratories

PVRC98.ppt 23

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PV Battery Storage Summary

Sandia National Laboratories

PVRC98.ppt 24

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Summary

Suggested Setpoints For Vented (Flooded) PV Batteries

Sandia National Laboratories

Parameter	Minimum Vented Lead-Antimony	Maximum/Equalize Lead-Antimony
PV Regulation Voltage (Vr) @ 25°C	14.4/2.40 vpc CV 14.7/13.7, 2.45/2.28 vpc Off/On	15.3/2.55 vpc CV 15.3/13.7, 2.55/2.28 vpc Off/On
Time at Vr	>2-hr	3 to 12-hrs
Array to Load Ratio	~1.3	
Low Voltage Disconnect (LVD)	11.4/1.9 vpc	
Temperature Coefficient V/°C/cell	-0.005	

PVRC98.ppt 25

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Summary

Suggested Setpoints For VRLA PV Batteries

Sandia National Laboratories

Parameter	Minimum VRLA	Maximum/Equalize VRLA
PV Regulation Voltage (Vr) @ 25°C (see manufacturers specs)	14.1/2.35 vpc CV or 14.4/2.40 vpc CV	14.1/2.35 vpc CV or 14.4/2.40 vpc CV
Time at Vr	>2-hr	12-hr
PV to Load Ratio	~ 1.3	
Low Voltage Disconnect (LVD)	11.5/1.92 vpc	
Temperature Coefficient V/°C/cell (see manufacturers specs)	-0.005	

PVRC98.ppt 26

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Summary
PV Battery Storage

Sandia National Laboratories

- Recharging the battery to a high SOC often results in better battery cycle-life
- Using appropriate charge controller setpoints for the battery used is important
- Component reliability needs to be high
- The PV array current to load current ratio needs to be adequate for the system design and solar resource

PVRC98.ppt 27

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Summary
PV Battery Storage

Sandia National Laboratories

- Battery enclosures need to protect the battery from extreme temperatures and flooding
- Using the right battery is important
- Boost charging the battery before installation is important

PVRC98.ppt 28

Photovoltaic Performance & Reliability Workshop
November 3 - 5, 1999
Cocoa Beach, Florida

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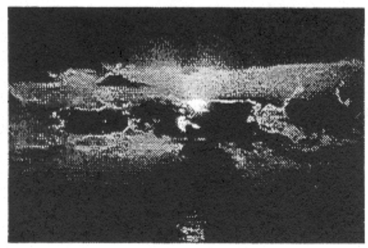

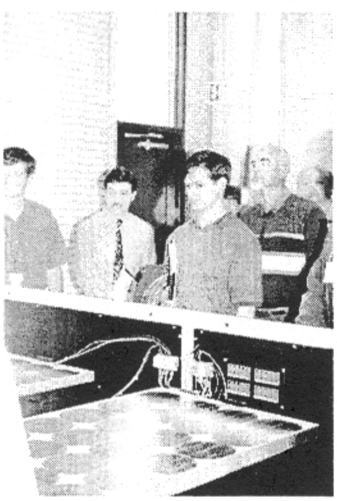

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