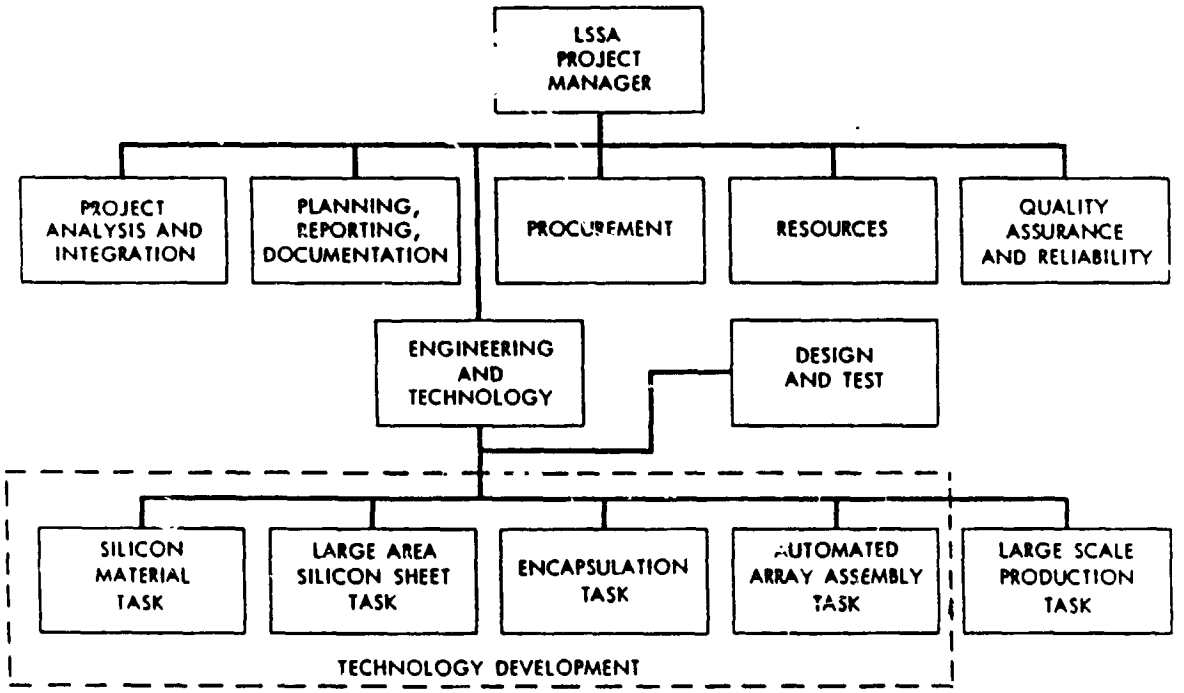
N87-16402

CRYSTALLINE-SILICON PHOTOVOLTAICS SUMMARY MODULE DESIGN AND RELIABILITY

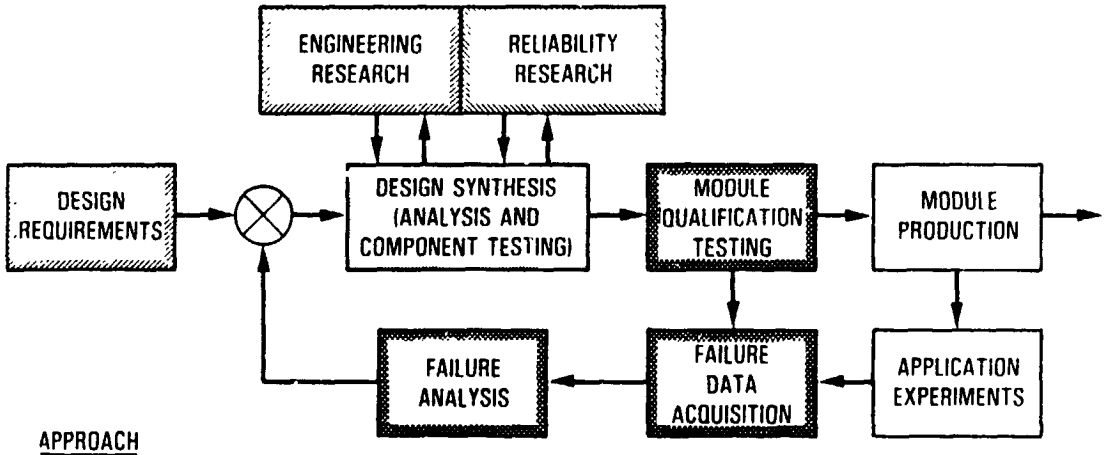
JET PROPULSION LABORATORY

R. G. Ross, Jr.

Low-Cost Silicon Solar Array Project
1975 Organization Chart



Reliability and Engineering Sciences Functional Organization (Closed-Loop Process)



APPROACH

- Derive requirements
- Synthesize designs
- Evaluate designs using laboratory and field tests
- Acquire and feed back performance data
- Develop improved technologies
- Use feedback and technology to improve designs

Design Requirement Generation

- Objective
  - Focus the development of low-cost long-life module technology toward commercial needs of future large-scale PV applications
- Approach
  - Define and develop module and array design requirements for future large-scale applications using private-sector experts and JPL in-house skills
    - Performance
    - Safety
    - Reliability
    - System (Array) Integration
  - Develop near-term versions of the requirements to serve as specifications for procurement of modules for testing and application experiments
  - Iterate the requirements with results fed back from testing experience

Module Design and Test Specifications

- JPL Crystalline-Si module design requirements have achieved international recognition and use

• Block I:	5-342	First Generation	Oct 75
• Block II:	5-342-1B	Second Generation	Dec 76
• Block III:	5-342-1C	Second Generation Update	May 77
• PRDA 38:	5101-65	Intermediate Load Center	Oct 77
• Block IV:	5101-16A	ILC (Third Generation)	Nov 78
	5101-83	Residential (Third Generation)	Nov 78
• Block V:	5101-161	ILC Applications	Feb 81
	5101-162	Residential	Feb 81

Design Requirements Accomplishments

- Definitive requirements developed in following areas:
  - Residential building codes (Burt Hill)
  - Utility design practices (Bechtel)
  - National electrical codes (UL)
  - Module safety (UL)
  - Product liability (Carnegie Mellon)
  - Wind loading levels (Boeing/CSU)
  - Array wiring safety (UL)
  - Module flammability (UL)
  - Hail impact levels (JPL)
  - Operating temperature levels (JPL)
  - Module reliability (JPL)
  - Array circuit design practices (JPL)
  - Array structural interfaces (Bechtel, Burt Hill, JPL)
  - System operational interfaces (JPL)

Design Requirements
Current Status and Future Needs

- Most module requirements for large-scale applications are in place for both C-Si and thin-film modules
  - Building code implications understood
  - National Electrical Code (Article 690) in place
  - Module safety requirements (UL 1703) in place
  - Operating temperature levels understood
  - Fire-resistance requirements in place
  - Array/system interface issues understood
  - Wind loading levels understood
  - Hail impact levels determined
  - JPL C-Si module design requirements internationally recognized
- Problem: Transferring the extensive existing technology base to new entries
- Problem: Crystalline-Si module specifications are not sufficient for thin-film modules

Engineering Sciences and Reliability Research

- Objective
  - Develop the engineering technology base required to achieve low-cost, efficient, and safe modules for large-scale applications
  - Develop the technology base required for reliable 30-year life modules
- Approach
  - Identify technology shortfalls through continuous feedback of results from design reviews, qualification tests, field application experiments, and laboratory investigations
  - Draw upon industry experts and JPL in-house experience to develop the generic technology advances required

Engineering Sciences Accomplishments

- Comprehensive design and construction technology base defined in following areas:
  - Electrical circuit analysis tools (JPL)
  - Module thermal design and test methods (JPL)
  - Module safety design practices (UL)
  - Electrical connection means (AMP, Motorola, Cannon)
  - Fire-resistant module construction practices (JPL, HITCO, Gila River)
  - Bypass diode integration practices (JPL, GE)
  - Array structural designs
    - Residential (Burt Hill, AIA, JPL)
    - Central station (Bechtel, JPL)
  - Array safety system designs (UL)
  - Array/power-conditioner interface characterization (JPL)

Reliability Research Accomplishments

- Definitive technology bases generated for:
  - Glass fracture strength (JPL)
  - Hail impact damage and probability (JPL)
  - Interconnect fatigue (JPL)
  - Soiling levels (JPL)
  - Cell fracture strength (JPL)
  - Hot-spot heating analysis and test methods (JPL)
- Substantial technology generated for:
  - Electrochemical corrosion analysis and test methods (JPL)
  - Bypass diode qualification test methods (JPL)
- Important technology generated for:
  - Electrical breakdown parameter dependencies (JPL, Bechtel, Hughes)
  - Corrosion resistance of C-Si and T-F cells (JPL, Clemson)
  - Module reliability synergisms (JPL, Wyle)

Engineering Sciences and Reliability Current Status and Future Needs

- Most engineering technologies are in place for both C-Si and thin-film modules
  - Structural/thermal design approaches and methods
  - Safety design practices
  - Circuit design approaches and analysis methods
  - System interfacing techniques
- Most technologies are in place for 30-year-life crystalline-Si modules. Exceptions include:
  - Long-term aging of electrical insulation systems
  - Long-term photothermal aging of rear surface films
  - Long-term corrosion of cell metallizations
  - Long-term stability of bonded interfaces
- Significant technology advances required to achieve 30-year-life thin-film modules

Module Development

- Objective
  - Facilitate the transfer of DOE sponsored technology developments into PV manufacturers and their products
  - Define and quantify design deficiencies as an important management tool to focus government and industry R&D efforts at key problems and to assess program performance against its goals
- Approach
  - Prepare module specifications reflecting future application requirements and encouraging state-of-the-art technology
  - Contract with private industry for module design and fabrication
  - Conduct detailed evaluation, test and failure analysis of delivered modules
  - Iterate design, design reviews, manufacture and tests until successful module qualification

Module Development Accomplishments

- Nurtured the development of 45 module designs within 15 PV manufacturers over a 10-year period
- Maintained R&D focus on critical-path problems by providing an internationally recognized assessment of PV module electrical performance and reliability
    - Developed unique facilities and techniques for performance assessment and failure analysis
    - Performed qualification tests on over 150 different module designs
        - Block I through Block V
        - DOE application experiments
        - Commercial (U.S. and foreign)
    - Conducted 435 major failure analyses involving 1200 reported design deficiencies

MODULE EVALUATION

ARCO Solar, Inc.

C. Gay

- Customer Is Key
  - Education
  - Experience
  - Confidence
- Relationship Between Laboratory Testing and Real World — Credibility
  - Predictable Energy Delivery
    - Carrisa Plains Within 3% Over 1 Year
  - Predictable Reliability
    - Less Than 1 Warranty Replacement Per 25,000 Modules (Over 500,000 Large Modules in the Field)