

PRELIMINARY STUDY: MOISTURE-POLYMER INTERACTION

JET PROPULSION LABORATORY

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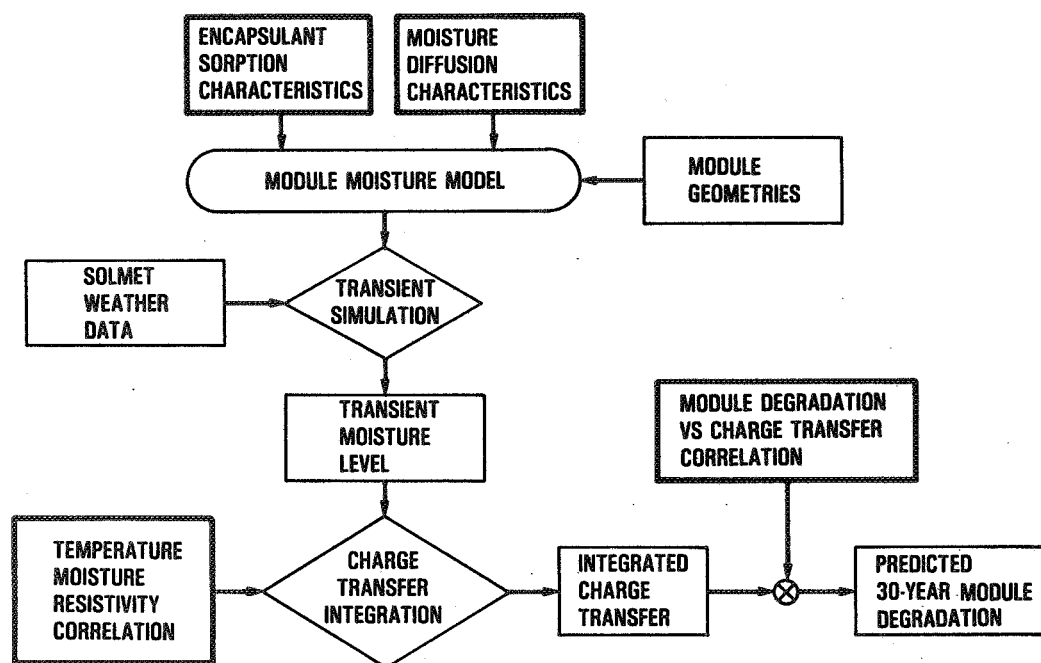
Study Objectives

To develop methodology for predicting module temperature, humidity and surface moisture level versus time in field environment

- Water sorption
- Moisture diffusion
- Simulation using SOLMET weather tape

To apply the above temperature-moisture prediction methodology together with electrochemical corrosion temperature-moisture dependence to predict module corrosion lifetime in the field

Simulation Flow Diagram

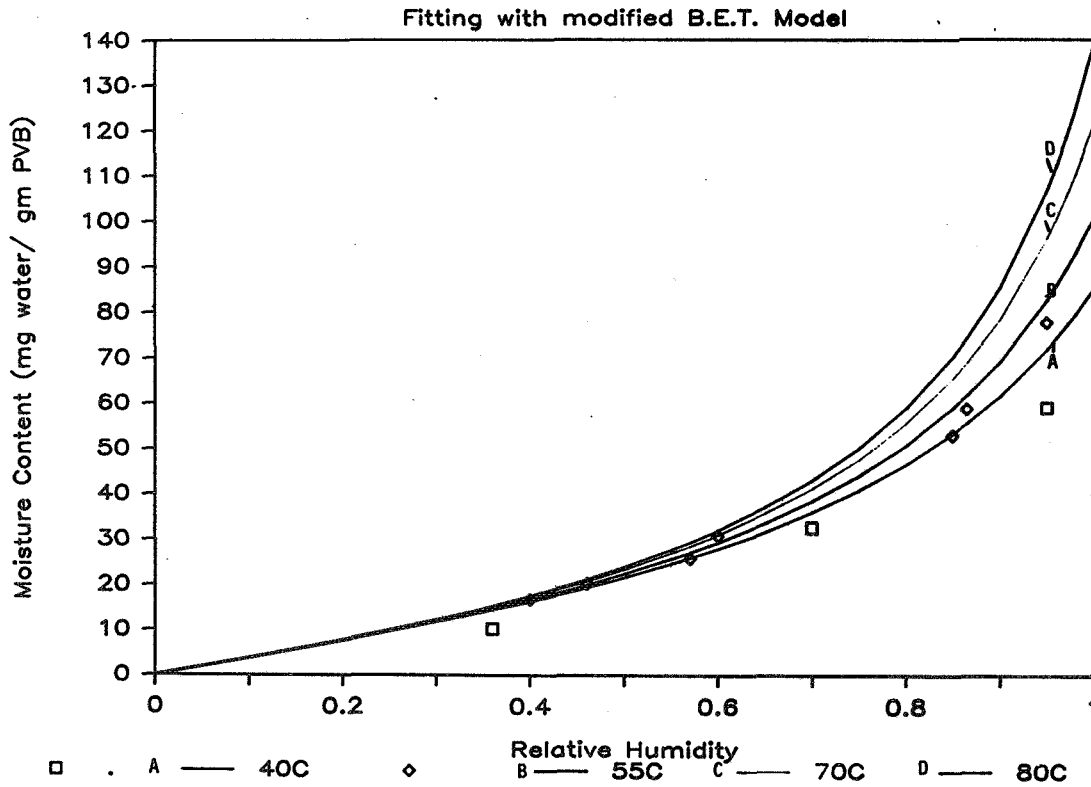


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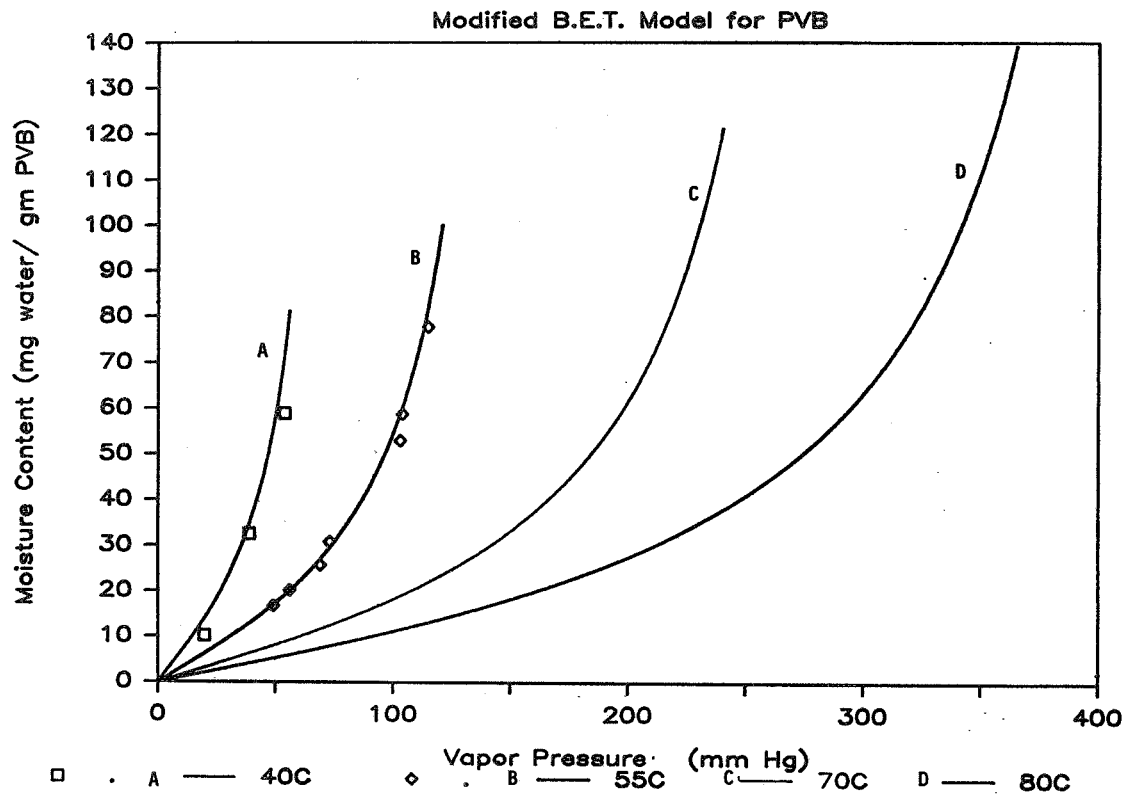
Sorption Study

- **Objective**
 - To establish an analytical model for predicting moisture sorption isotherms for relevant polymers
- **Approach**
 - Gravimetric measurements using a Cahn balance
 - Isothermal system: humidity chamber
 - Relative humidity from 40% to 95%, no liquid water
 - Data fitting with an analytical model (modified B.E.T. equation)

Water Sorption for PVB



Water Sorption Isotherms



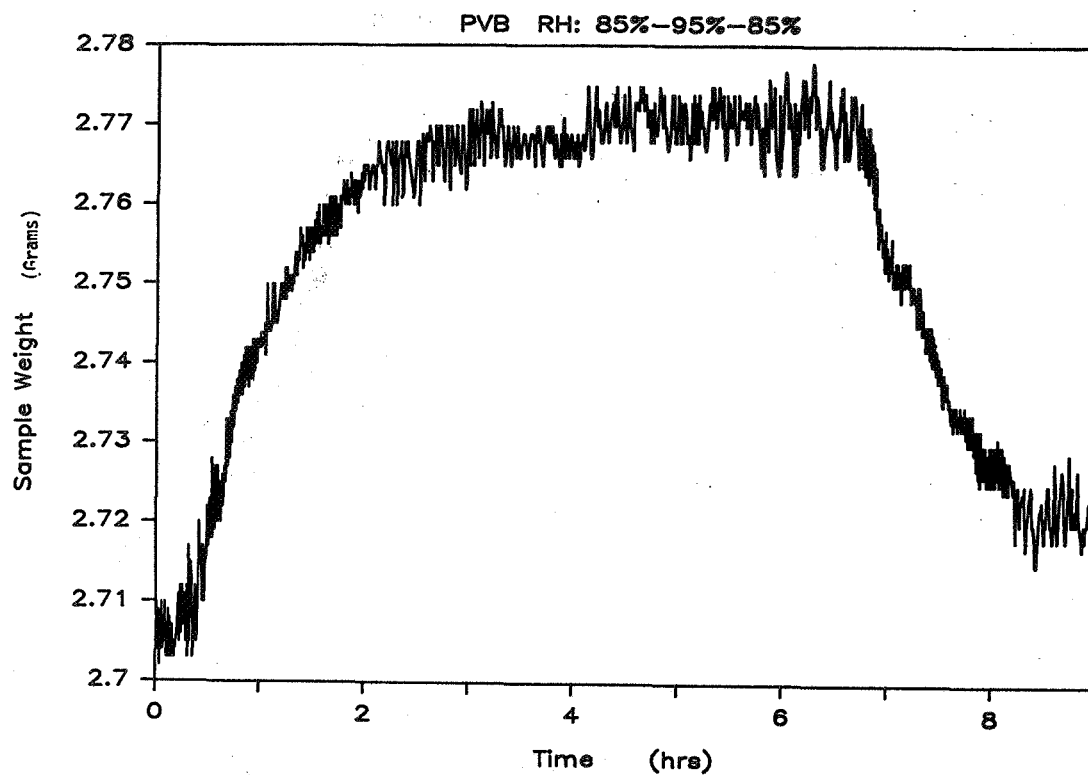
Moisture Sorption

- **Status**
 - Limited samples were used (PVB)
 - Reasonable data fitting with a modified B.E.T. equation
- **Required R&D**
 - Expanded sorption data base for different materials, composite layers and conformal coatings
 - Sorption-desorption in non-isothermal conditions
 - Kinetics and thermodynamics of adsorption/absorption (both liquid and vapor water)
 - Factors influence moisture sorption in polymer; plasticizer, cross-linking agent
 - Free-to-bound water transformation

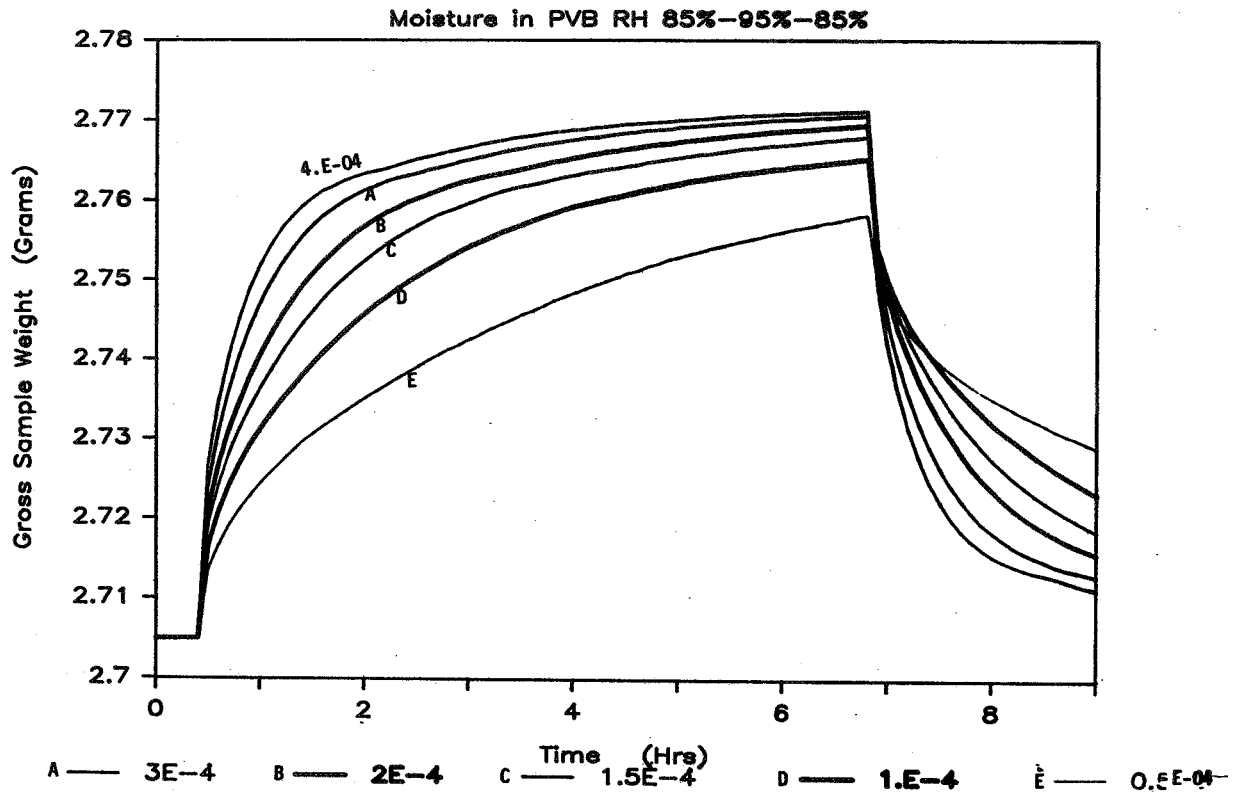
Moisture Diffusion

- **Objective**
 - **To develop a moisture transport model and diffusion/permeation parameters**
- **Approach**
 - **Transient experimental data based on sorption measurements**
 - **Nodal network representation of Fick's diffusion model**
 - **100-layer model**
 - **Isothermal system**
 - **Parametric iteration of constant diffusivity levels**
 - **Determination of diffusivity based on transient data**
 - **To establish equations to correlate diffusivity/permeability as a function of temperature and moisture content**
- **Status**
 - **Diffusivity increases with moisture content in PVB**
 - **Arrhenius-type variation with temperature**
 - **Good correlations between data and model**
- **Required R&D**
 - **Moisture diffusion in composite encapsulants**
 - **Diffusion of unbound water**
 - **Bulk water movement**
 - **Transition of bound and unbound water**
 - **Apparent diffusivity**
 - **Non-isothermal system**
 - **Models for simultaneous heat and mass transfer**
 - **Thermal diffusion**
 - **Factors affecting moisture diffusion and permeation.**

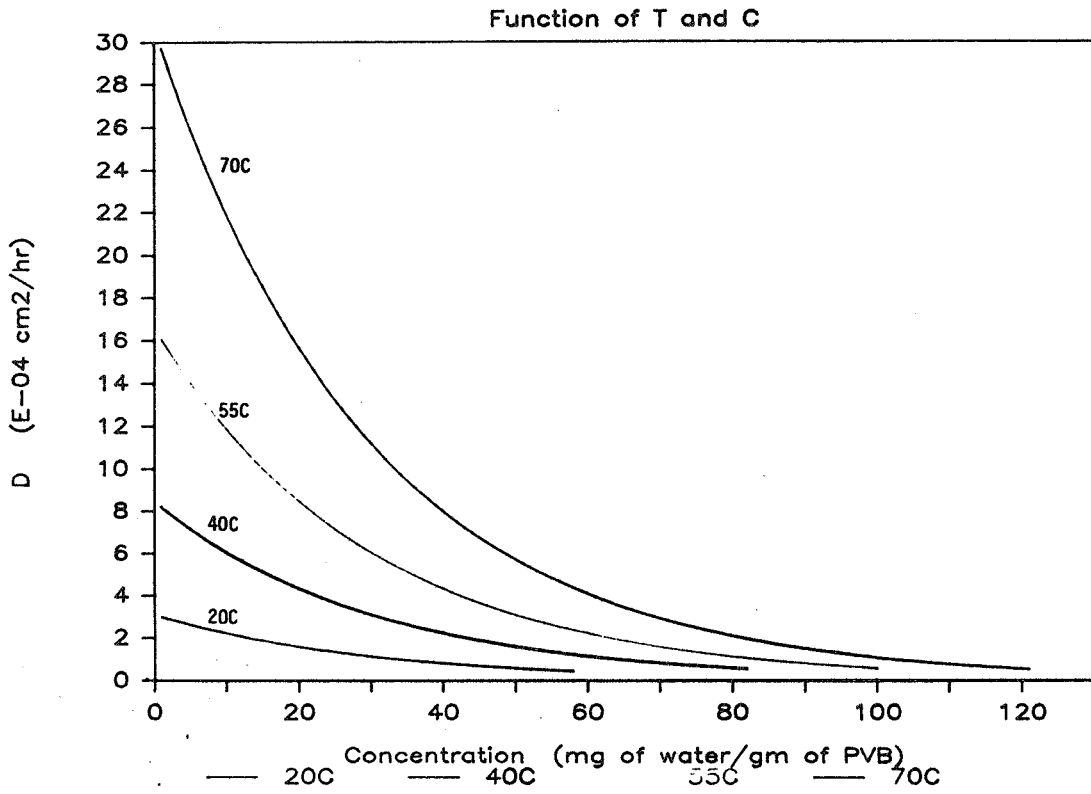
Moisture Sorption-Desorption



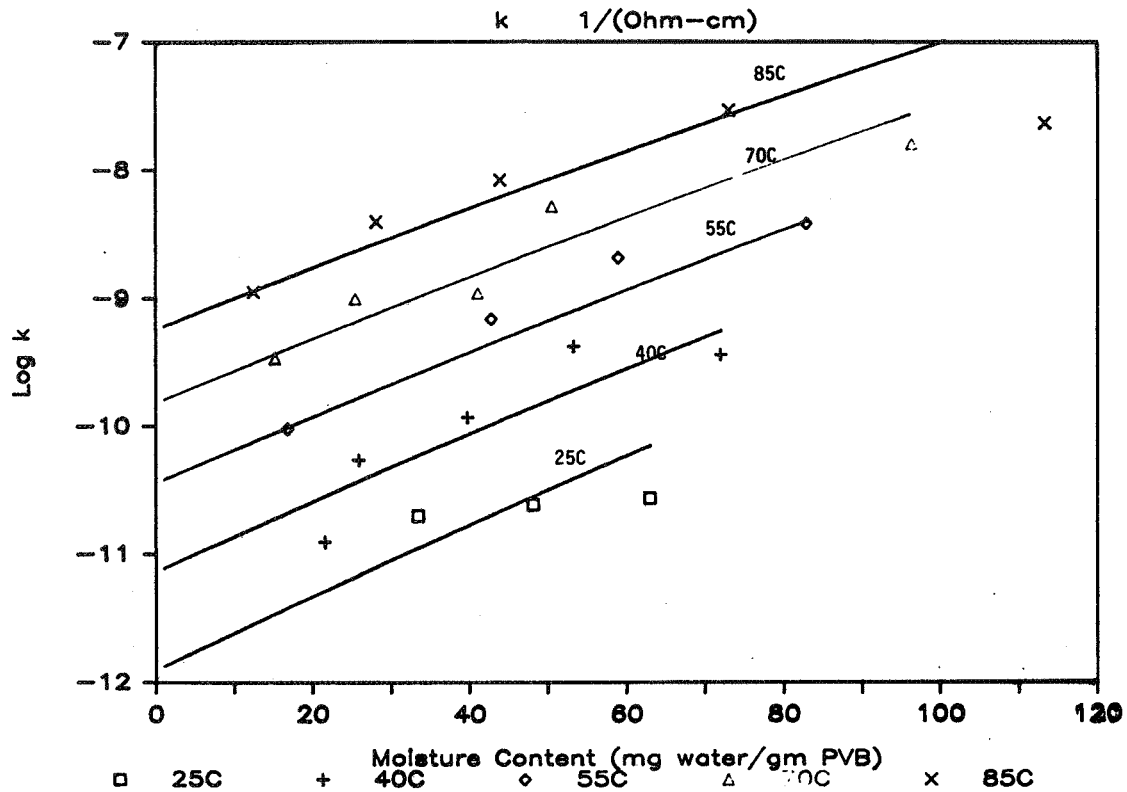
Diffusivity Simulation at 55°C



Diffusivity of Moisture in PVB



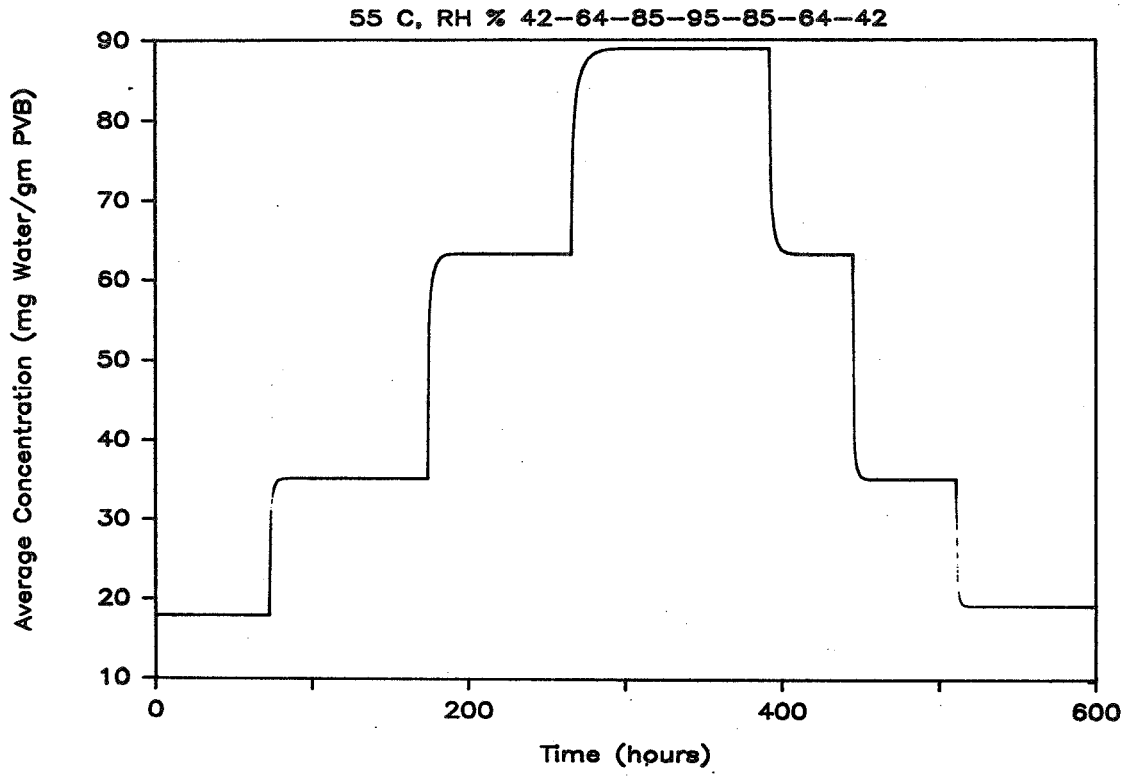
Bulk Conductivity of PVB



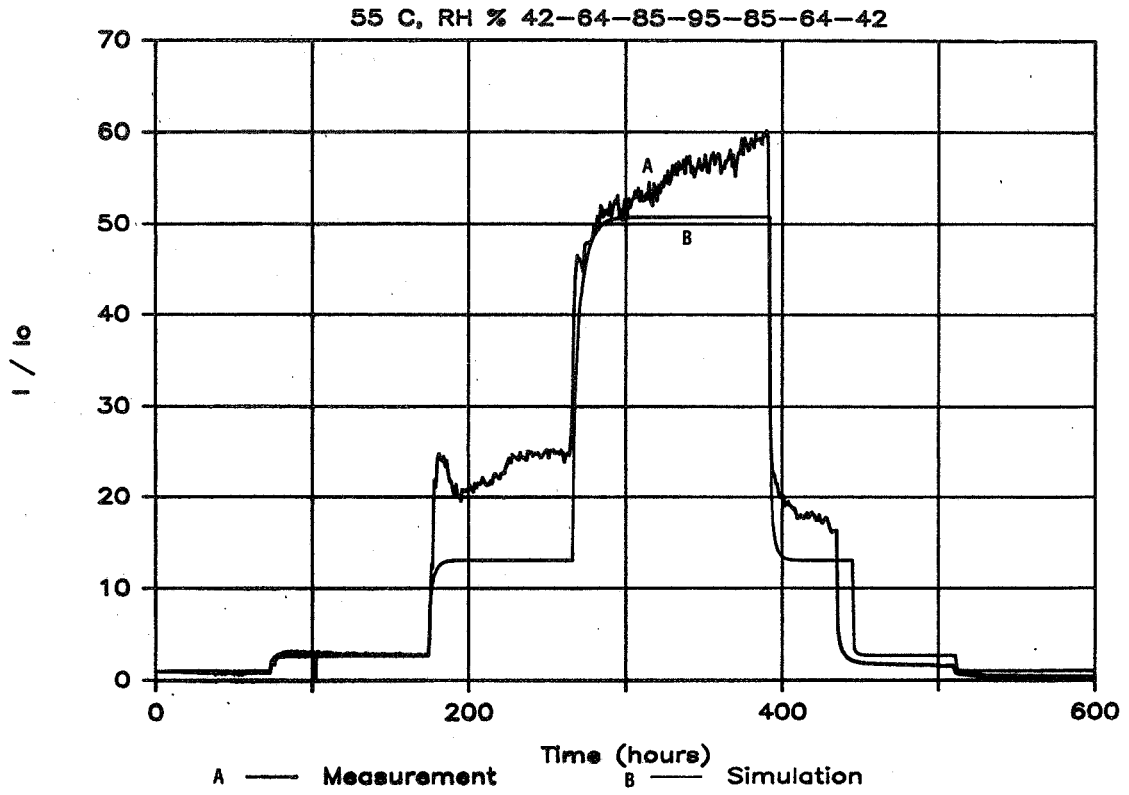
Electrochemical Corrosion

- Objective
 - To simulate module leakage current vs time in operating environment
- Approach
 - Construct preliminary analytical model
 - Conduction across encapsulant
 - No surface resistance, no lateral volumetric conduction
 - Include equations for sorption and diffusivity
 - Nodal network analysis using thermal analyzer SINDA
 - Equation to represent bulk ionic conductivity as a function of temperature and moisture content
 - Exercise model with transient chamber boundary conditions
 - Exercise model with SOLMET field data

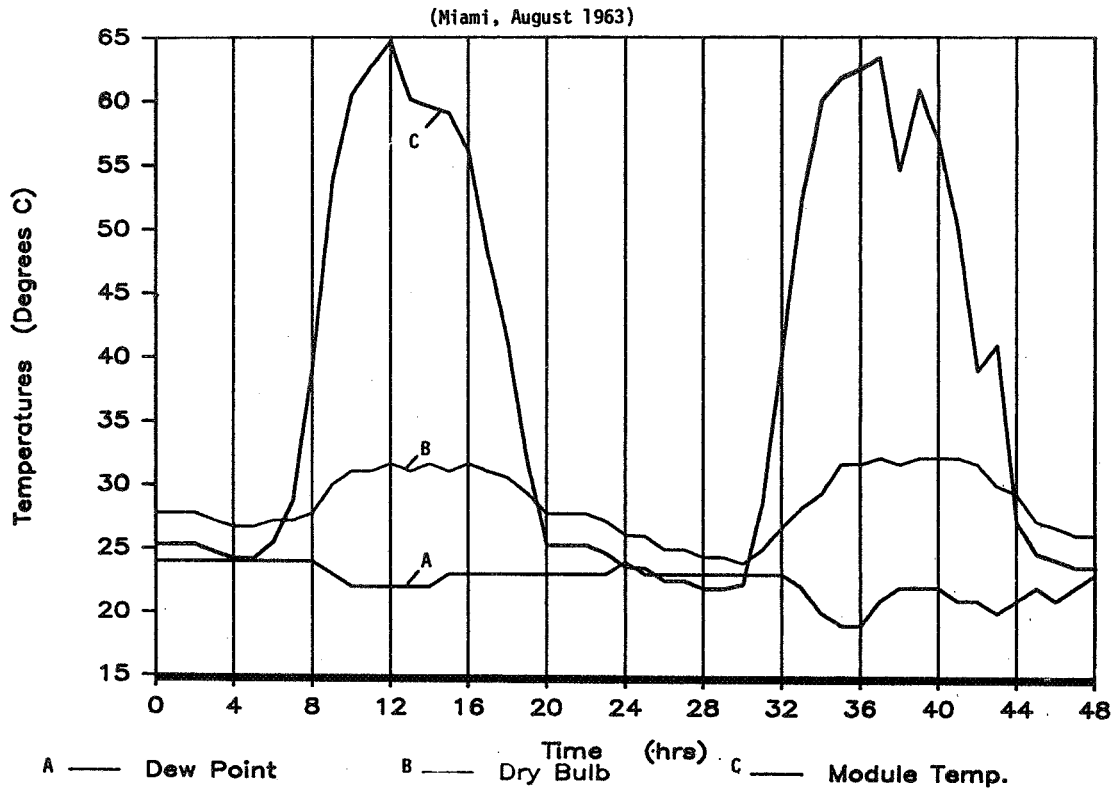
Moisture Content, PVB



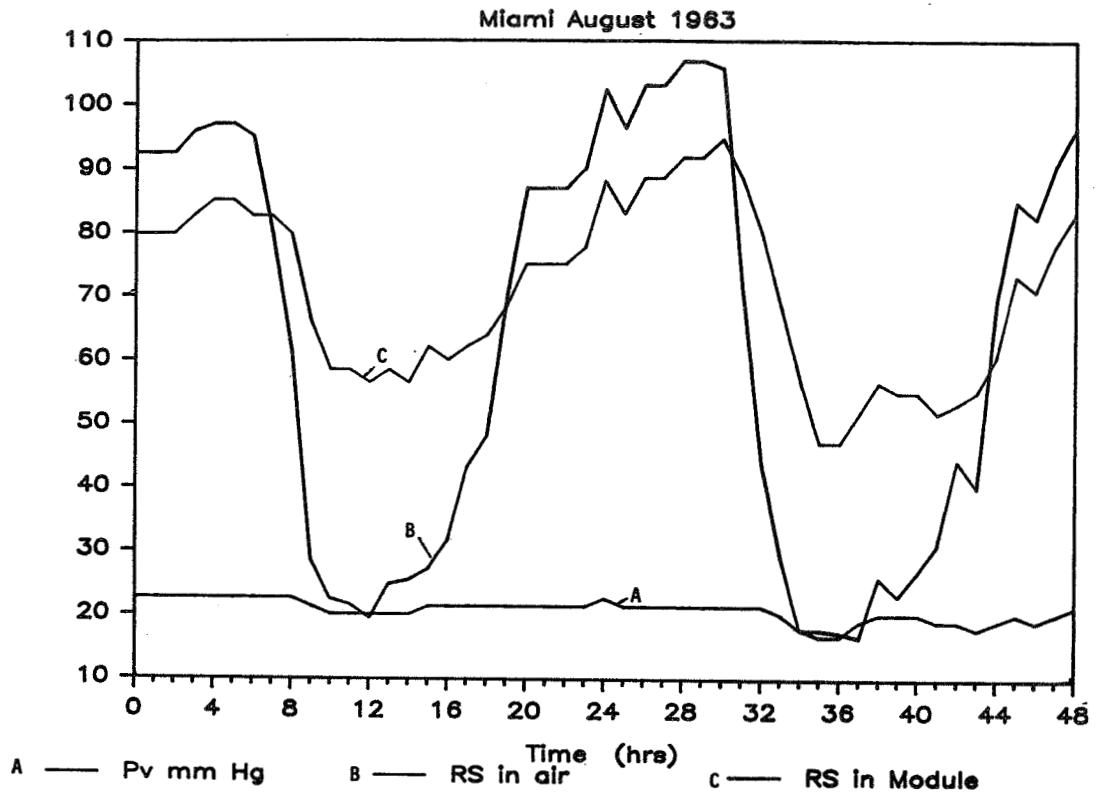
Normalized Leakage Current



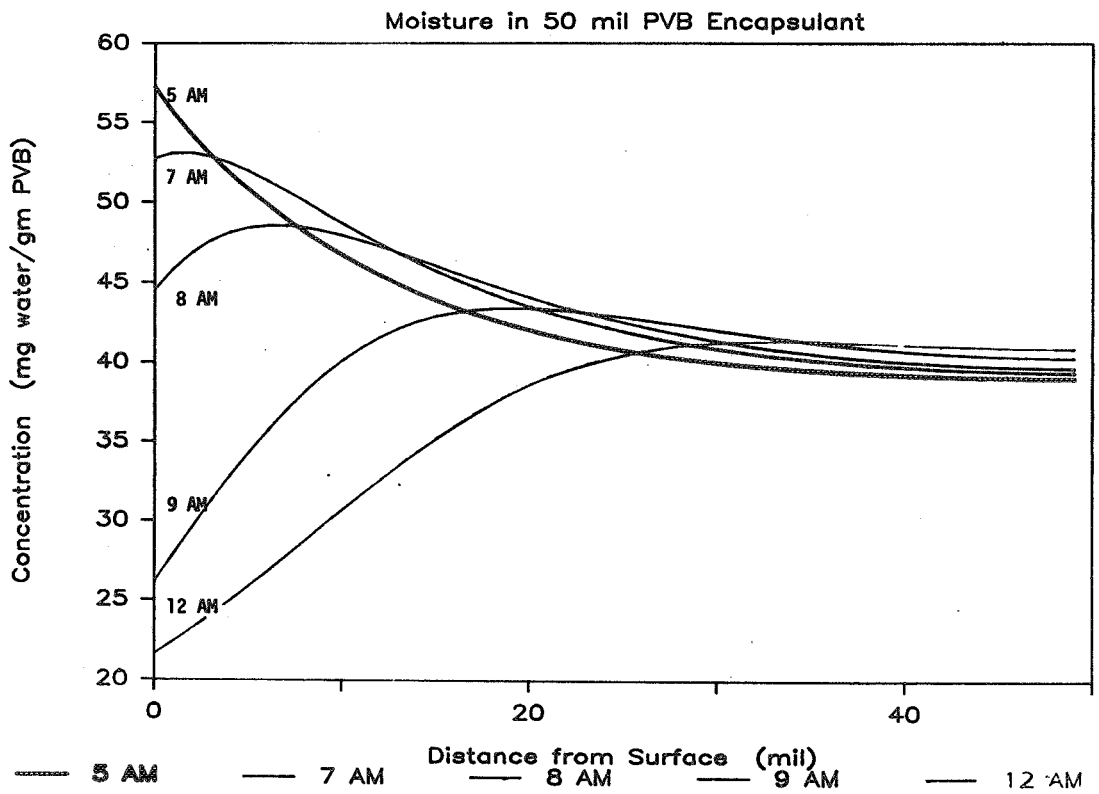
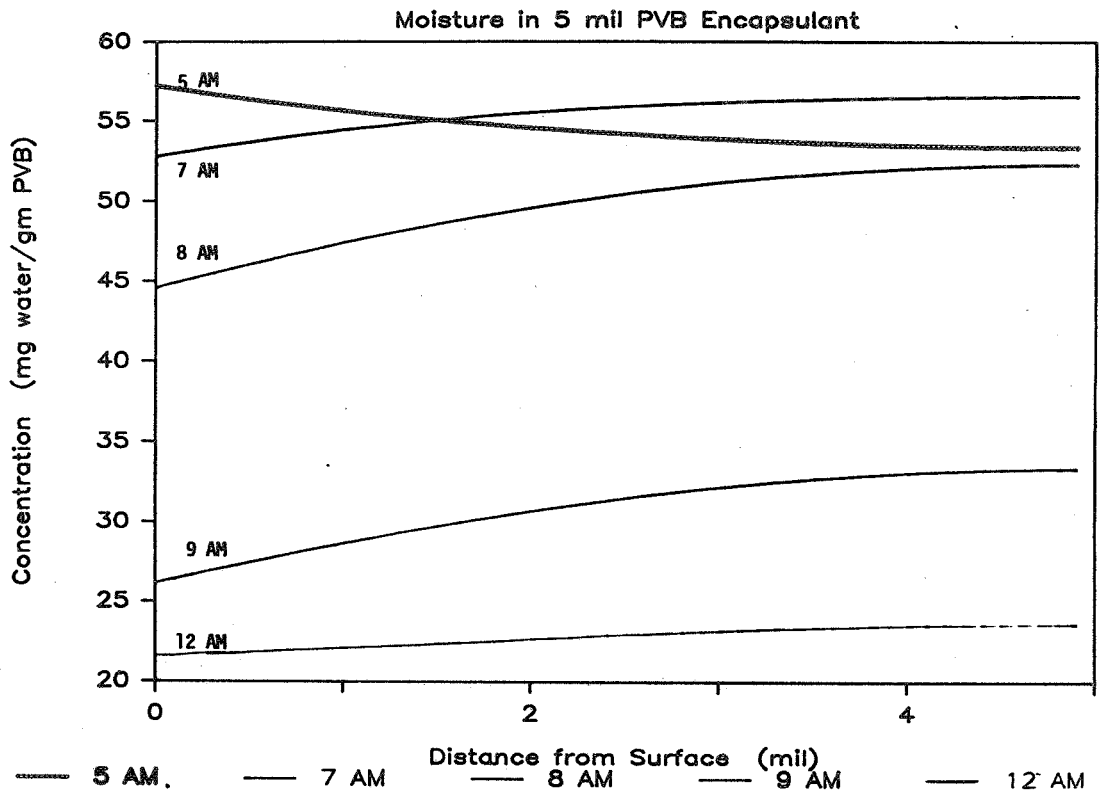
Temperature Profiles



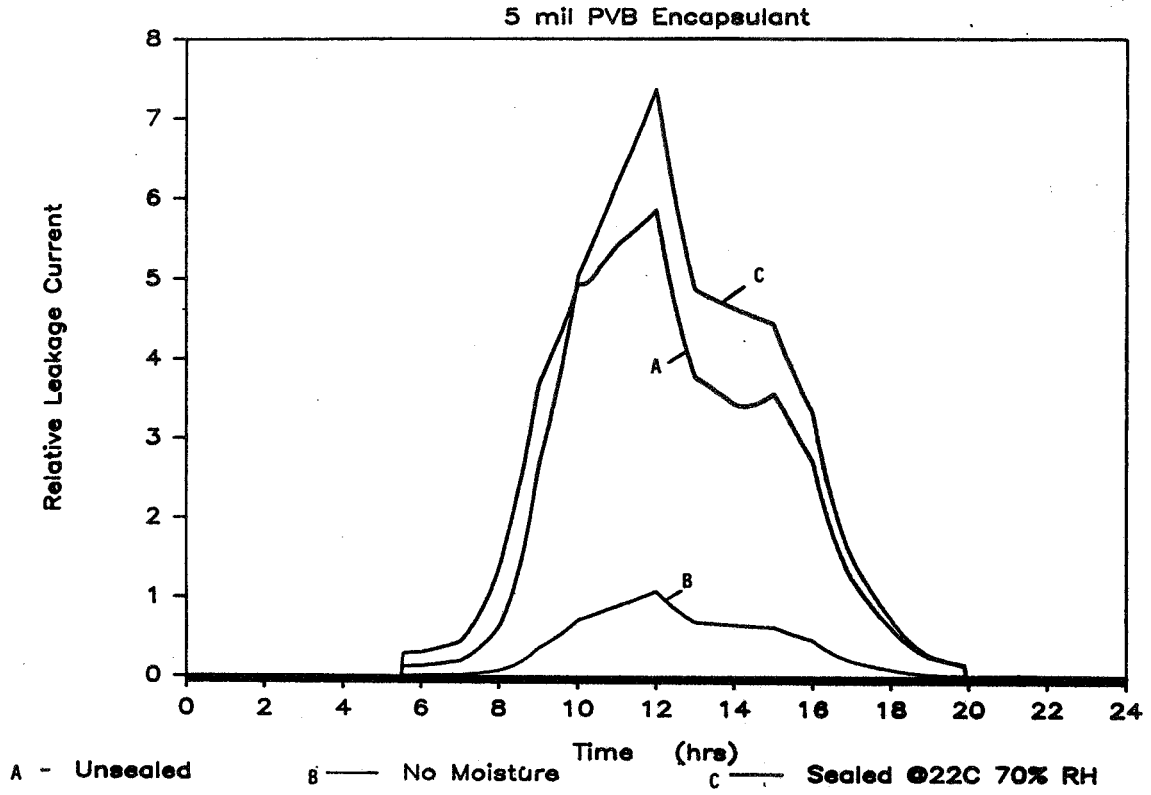
Vapor Pressure and Relative Saturation



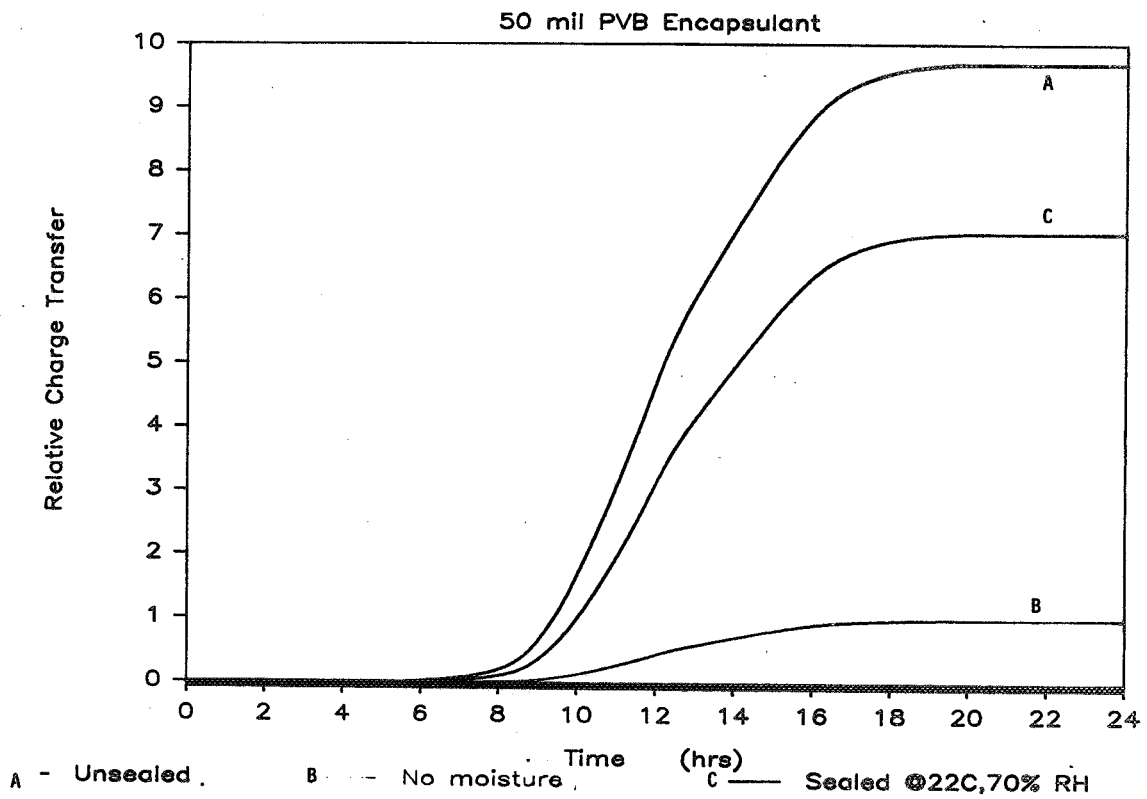
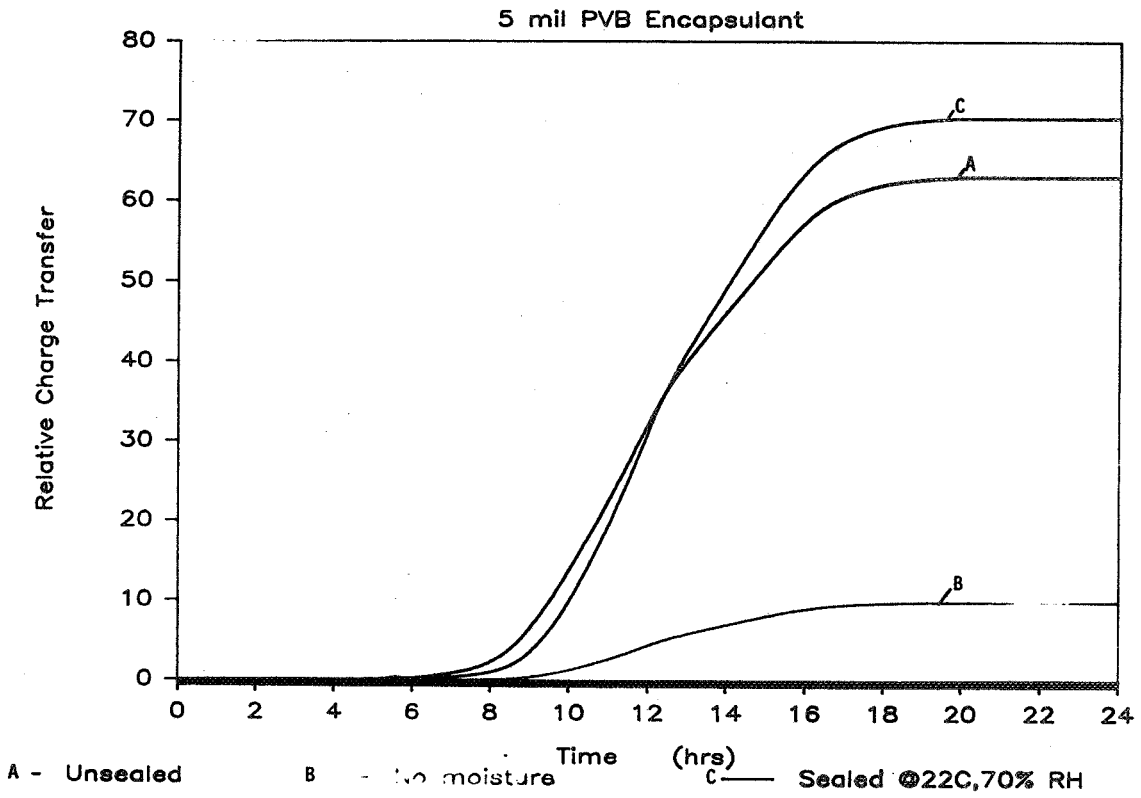
Concentration Distribution



Leakage Current in Field



Charge Transfer in Field



Summary

- **Realistic lifetime prediction appears to be feasible**
- **Refinements in prediction techniques are required**
- **Research areas:**
 - **2-dimensional ionic conduction model**
 - **Composite layers**
 - **Non-isothermal system**
 - **Effects of liquid water**
 - **Interfacial adsorption/absorption**