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Corrosion of Electronics: Use of Accelerated Testing Predict Reliability

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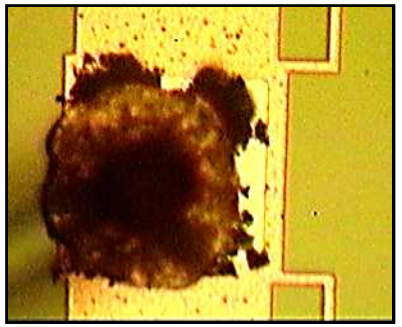
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

What is corrosion?

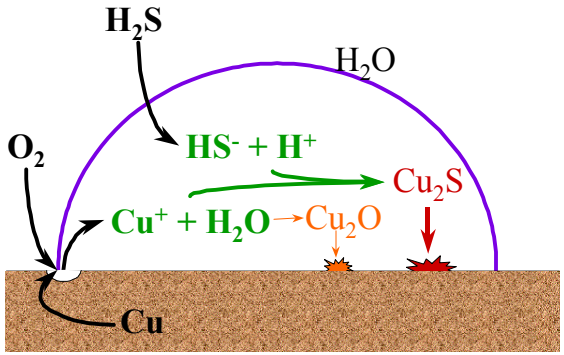
Environmental degradation of materials



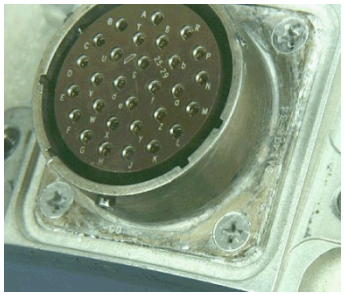
- Aqueous (general & localized attack)
  - electrochemical
  - oxidation / reduction
- Atmospheric
  - gas-metal reaction (slow)
  - condensed phase electrochemical
  - pollutant gasses (ppt levels of H_2S, NO_2, Cl_2 …)

Processing

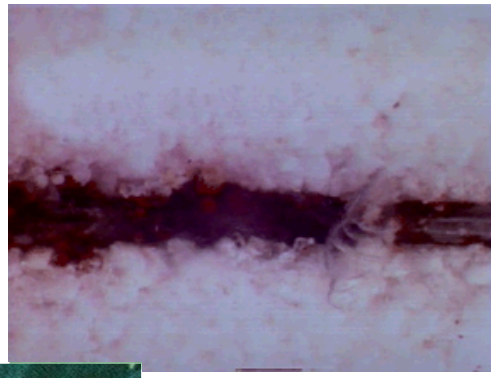
Use

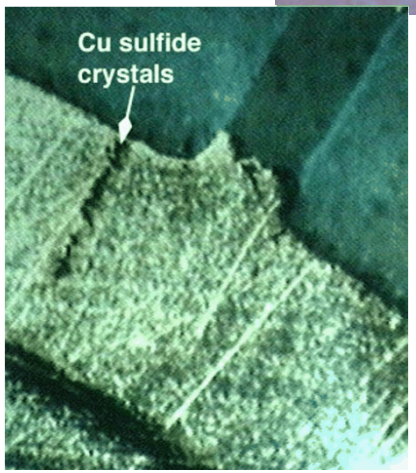


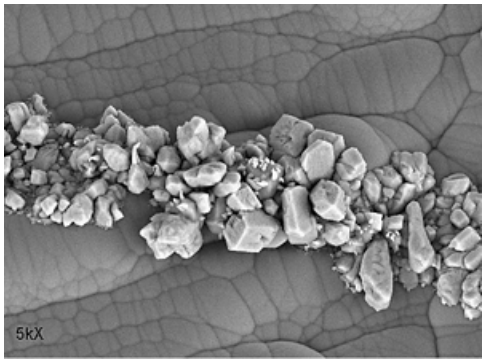
Corrosion normally occurs due to defects or unexpected environments

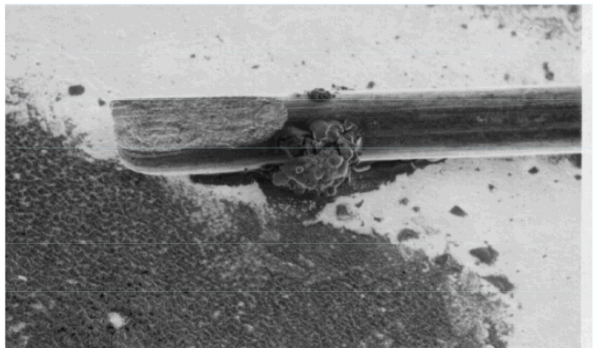


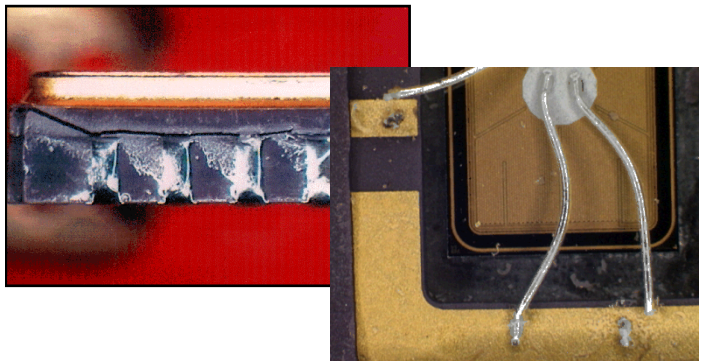
Cruise missile fuel line

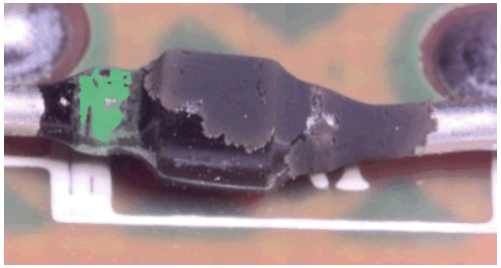


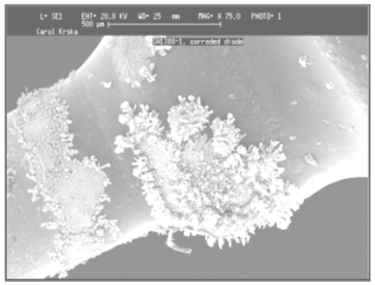




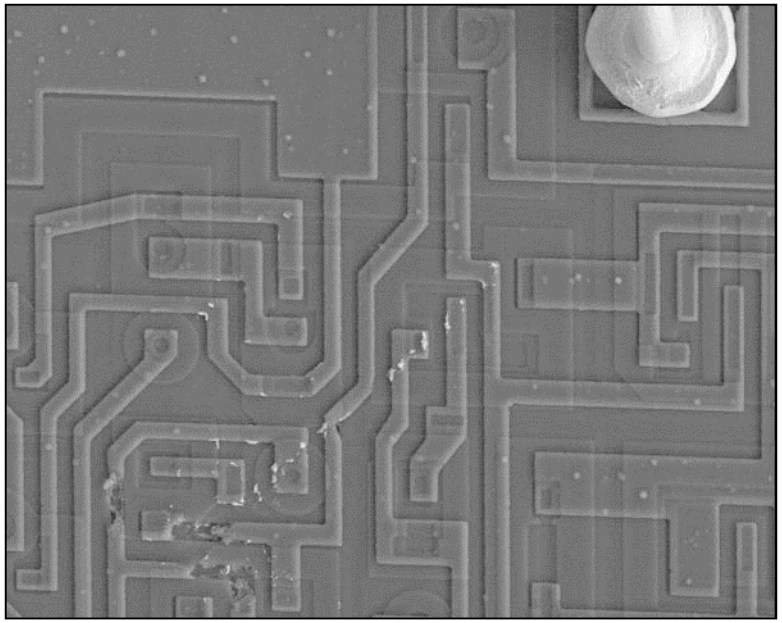


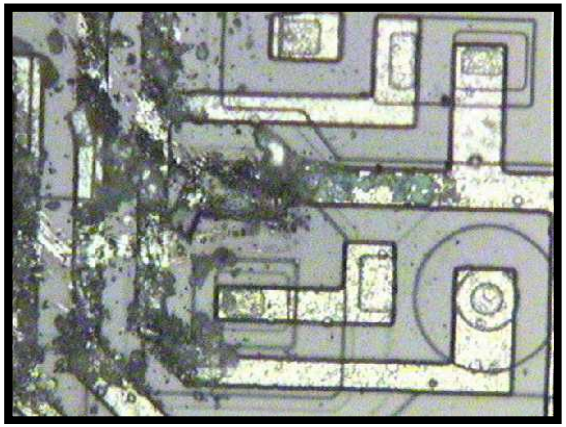






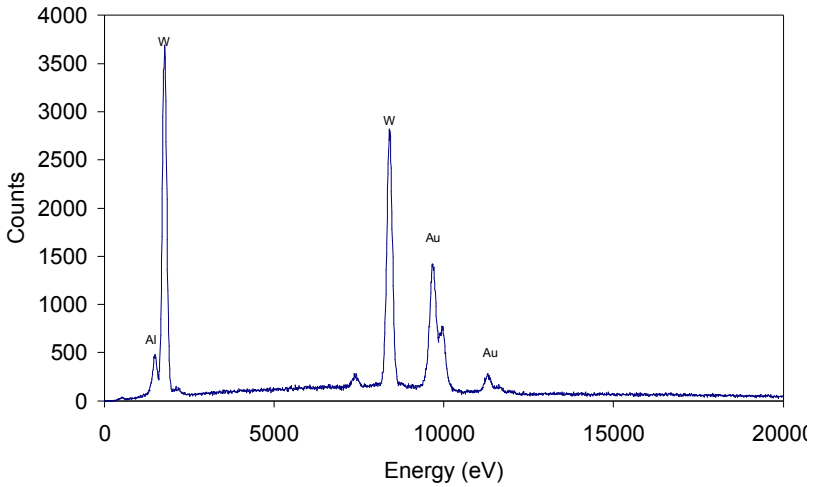
A plastic encapsulated IC failed after 5 years in dormant storage.





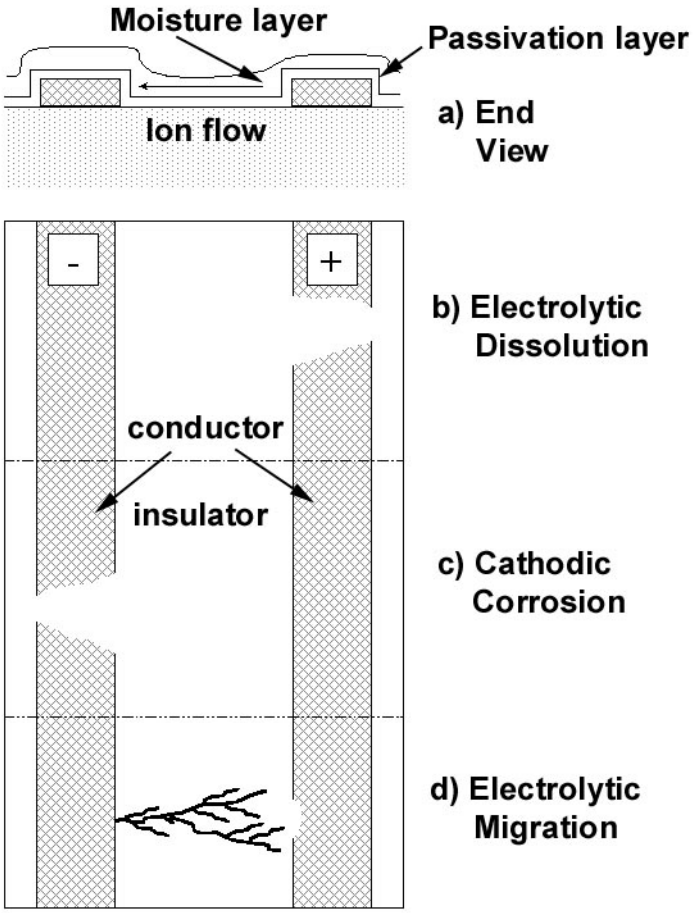
Defects:

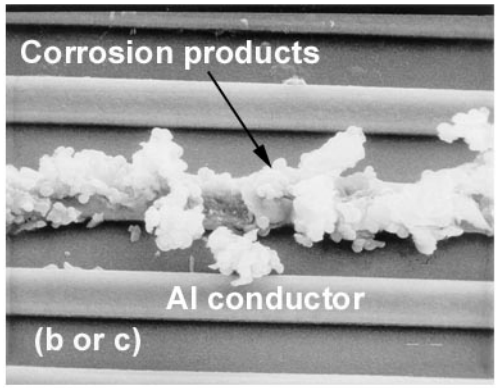
- Damaged passivation
- Au (galvanic couple)

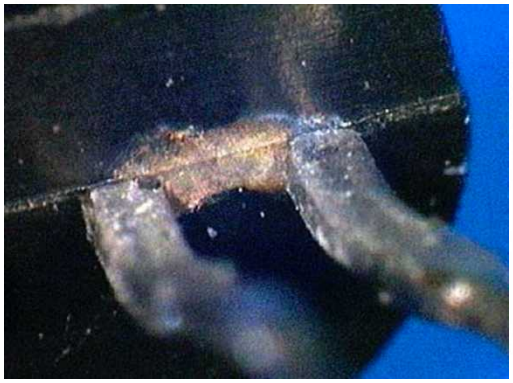


Several non-traditional corrosion mechanisms exist in microelectronics that involve electrical bias

- **Electrolytic dissolution**
- **Cathodic corrosion (alkalization)**
- **Electrolytic migration**

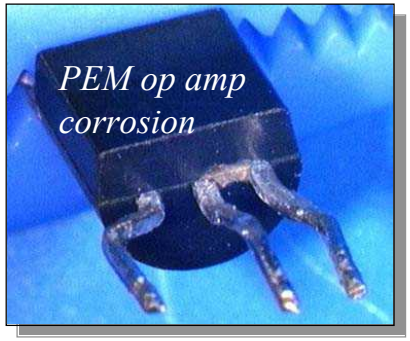




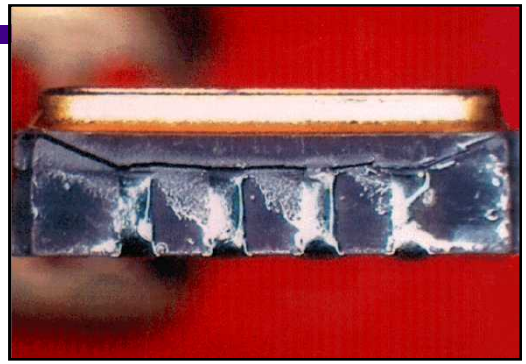


Conditions required for electrolytic migration

- Applied voltage
  - powered system
- Susceptible alloy
  - Ag used in ground plane
  - Solder
  - Copper
- Conductive surface
  - flux residue (activator)
- Electrolyte
  - High humidity
    - Temperature cycling
  - Seacoast environment (NaCl)



Corrosive environments can contact metallization features

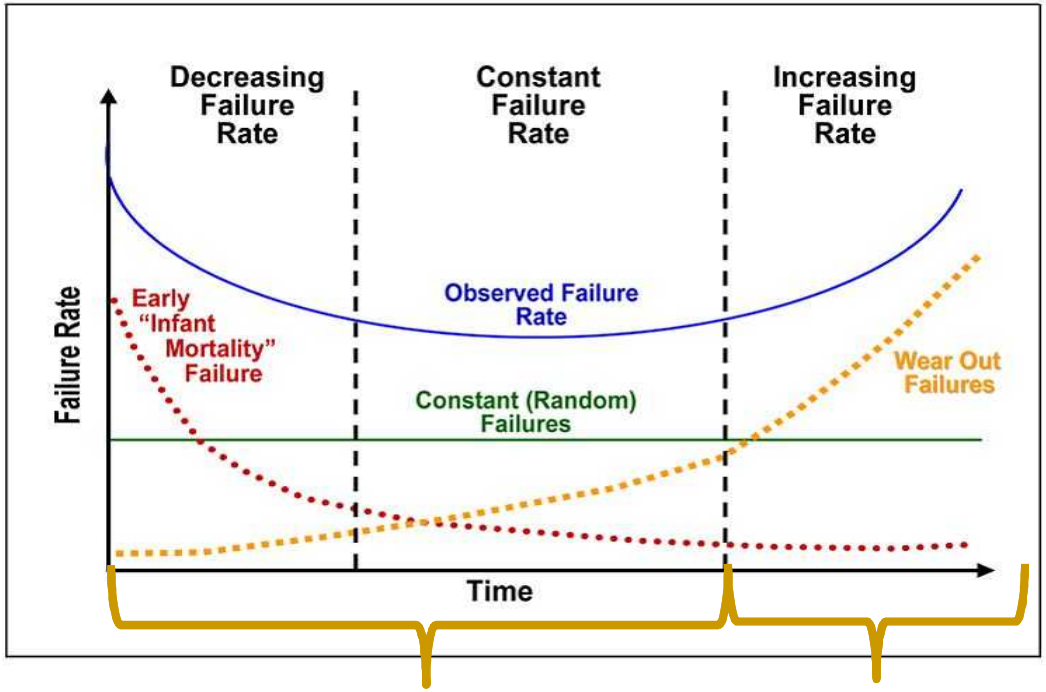


- **Breach in hermetic packaging in CHP**
- **Use of encapsulants in PEMs with high water permeability**
- **Specific unintended exposures (e.g., military)**
  - **high T, RH, [Cl-] possible**

Materials Degradation Affects Reliability

Probability of failure-free performance, item's useful life, or a specified timeframe specified environmental duty-cycle conditions.

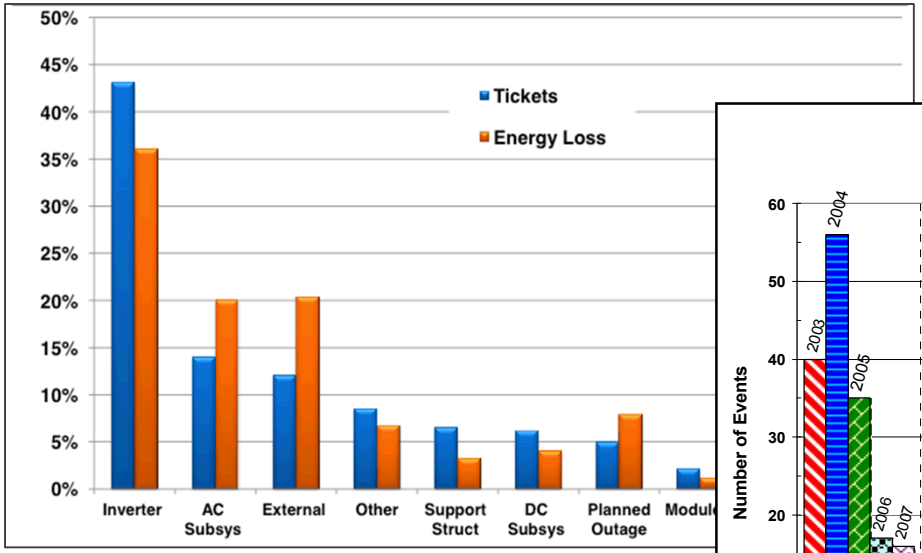
Reliability ⟷ Cost



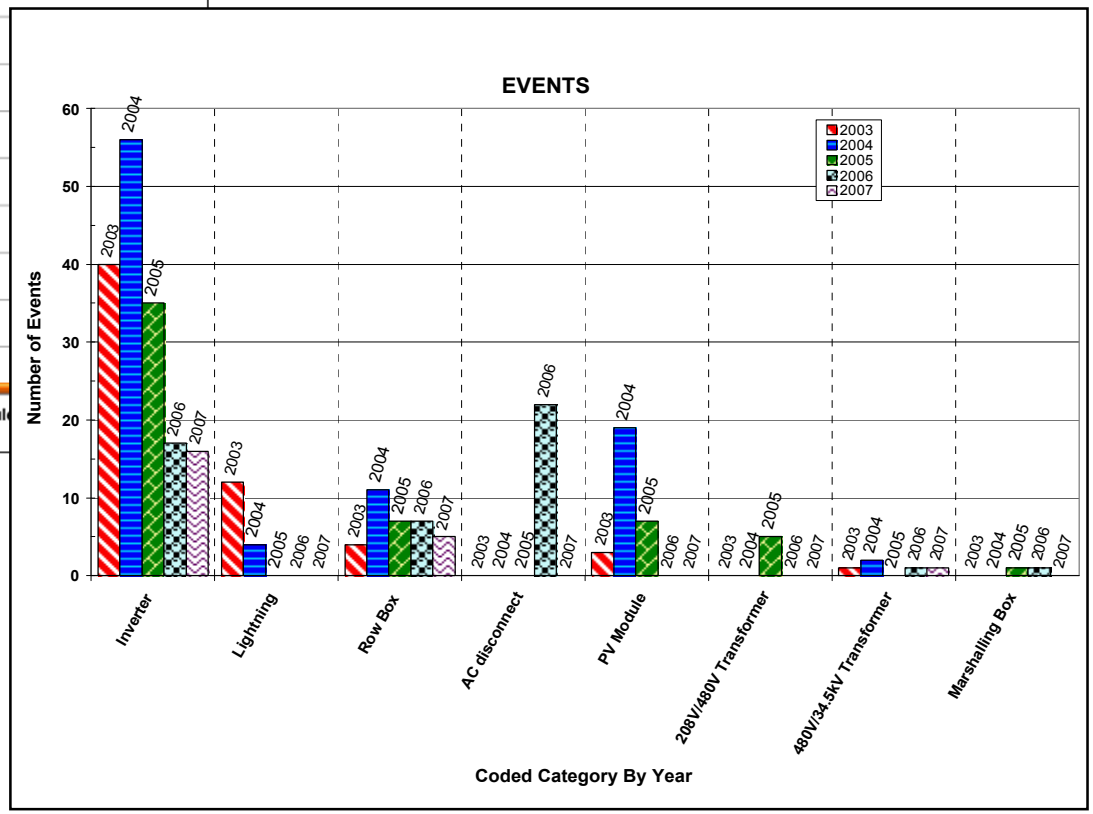
Accelerated testing plays a key role in determining reliability

- **Must be applicable to failure modes**
  - **Reproduce field failures**
- **Acceleration factor**
  - **Range of stresses**
  - **Long term tests**

The inverter is a significant contributor to reliability issues



Sun Edison – Owner/Operator (A. Golnas, "PV System Reliability: An Operator's Perspective," in 38th Photovoltaic Specialists Conference, Austin, TX, Jun. 2012, pp. 1–32.)



Tucson Electric Springerville Plant.
Sandia Study

What is ALT & why?

What?

- Component life tests
- High stresses
  - Single or combined
  - Activate “appropriate” failure modes
  - Measureable
- Time compression (cyclic stresses)
- Failure analysis

Why?

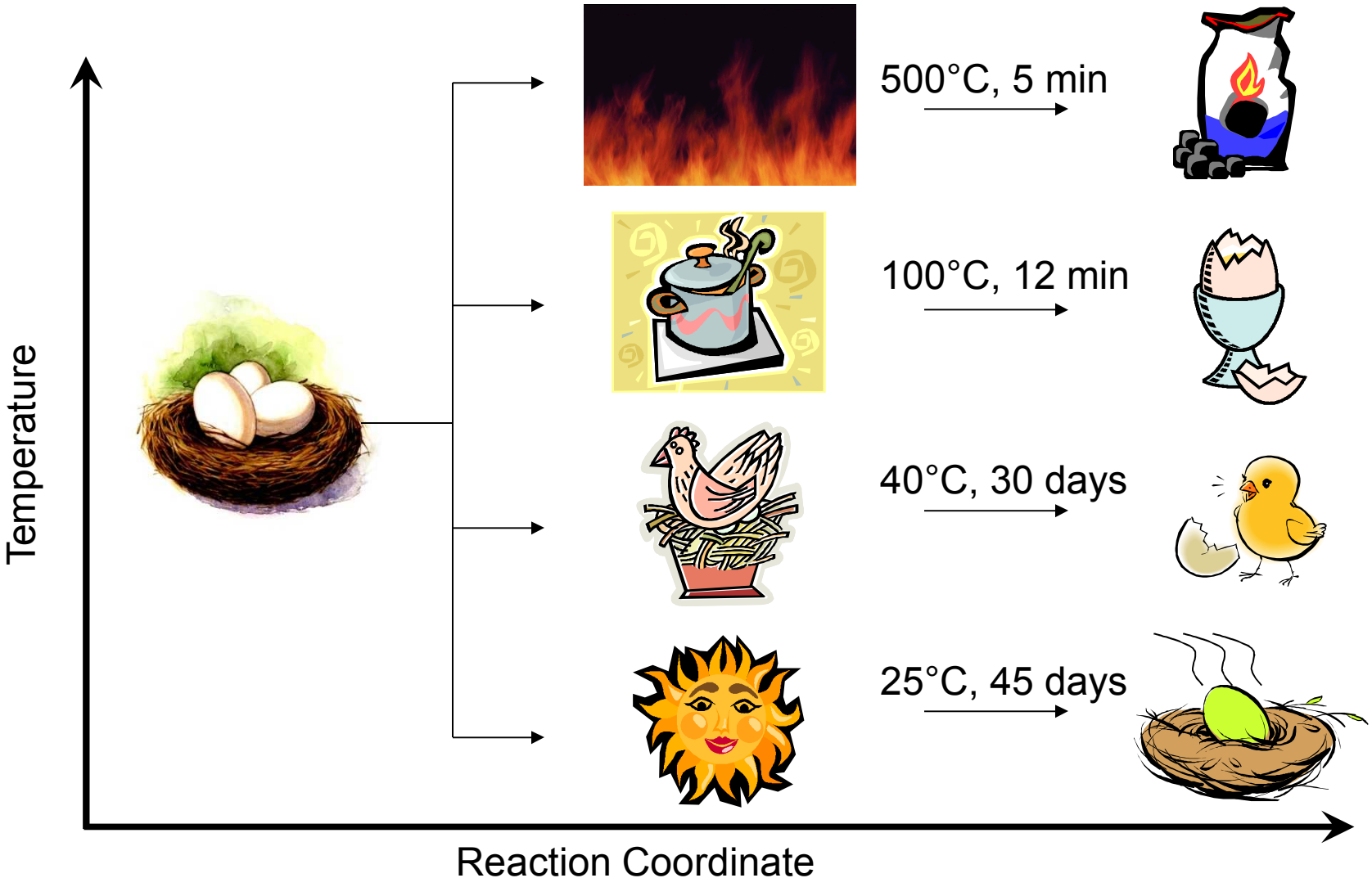
- Time
- Full system is expensive and complicated

Failure Modes for Crystalline Silicon
(John Wolgemuth – BP Solar)

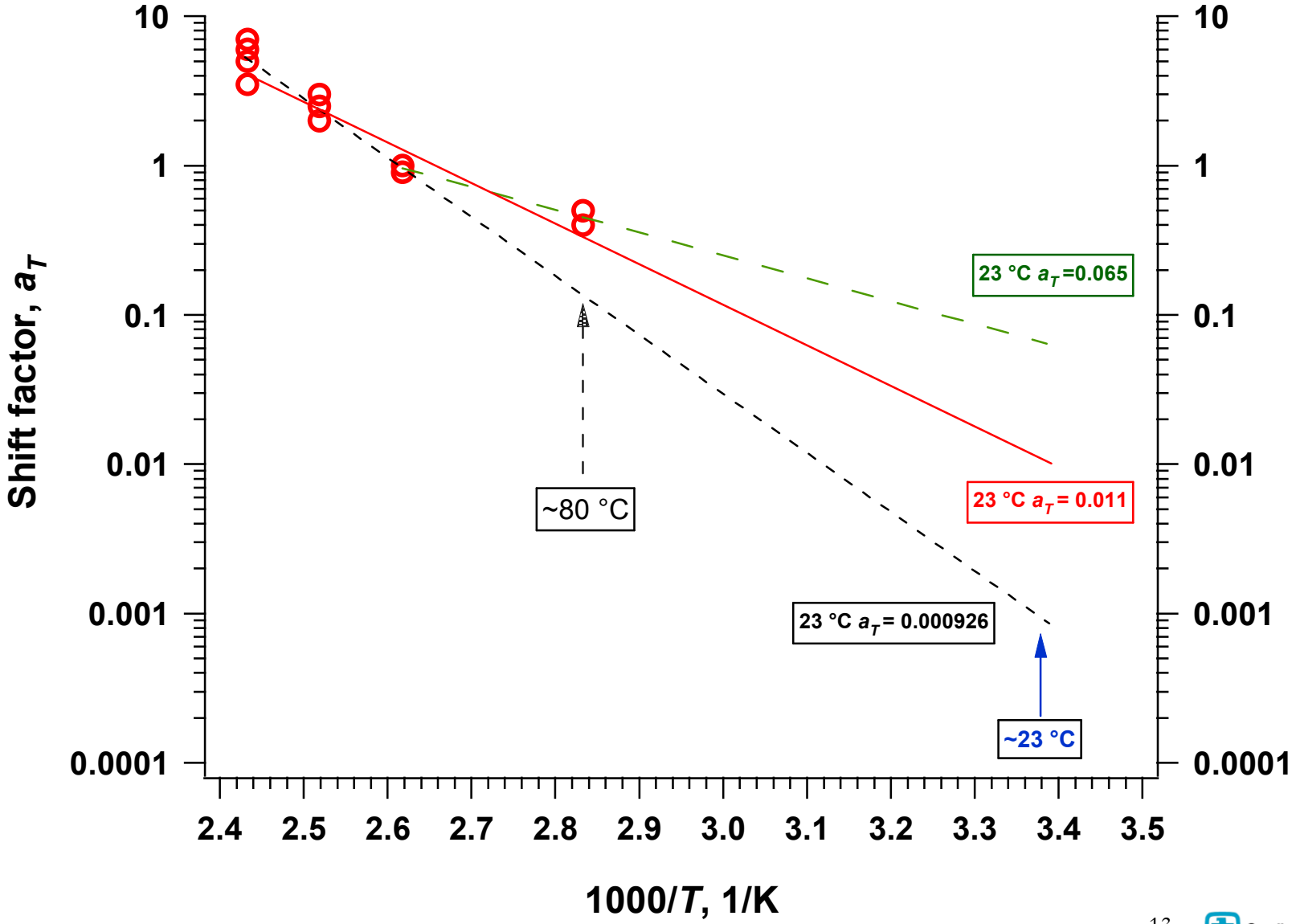
- Broken interconnects
- Broken Cells
- Corrosion
- Delamination and/or loss of elastic properties
- Encapsulant discoloration
- Solder bond failures
- Broken glass
- Hot Spots
- Ground faults
- Junction box and module connection failures
- Structural failures

Would you expect a single test to capture all of the expected failure modes?

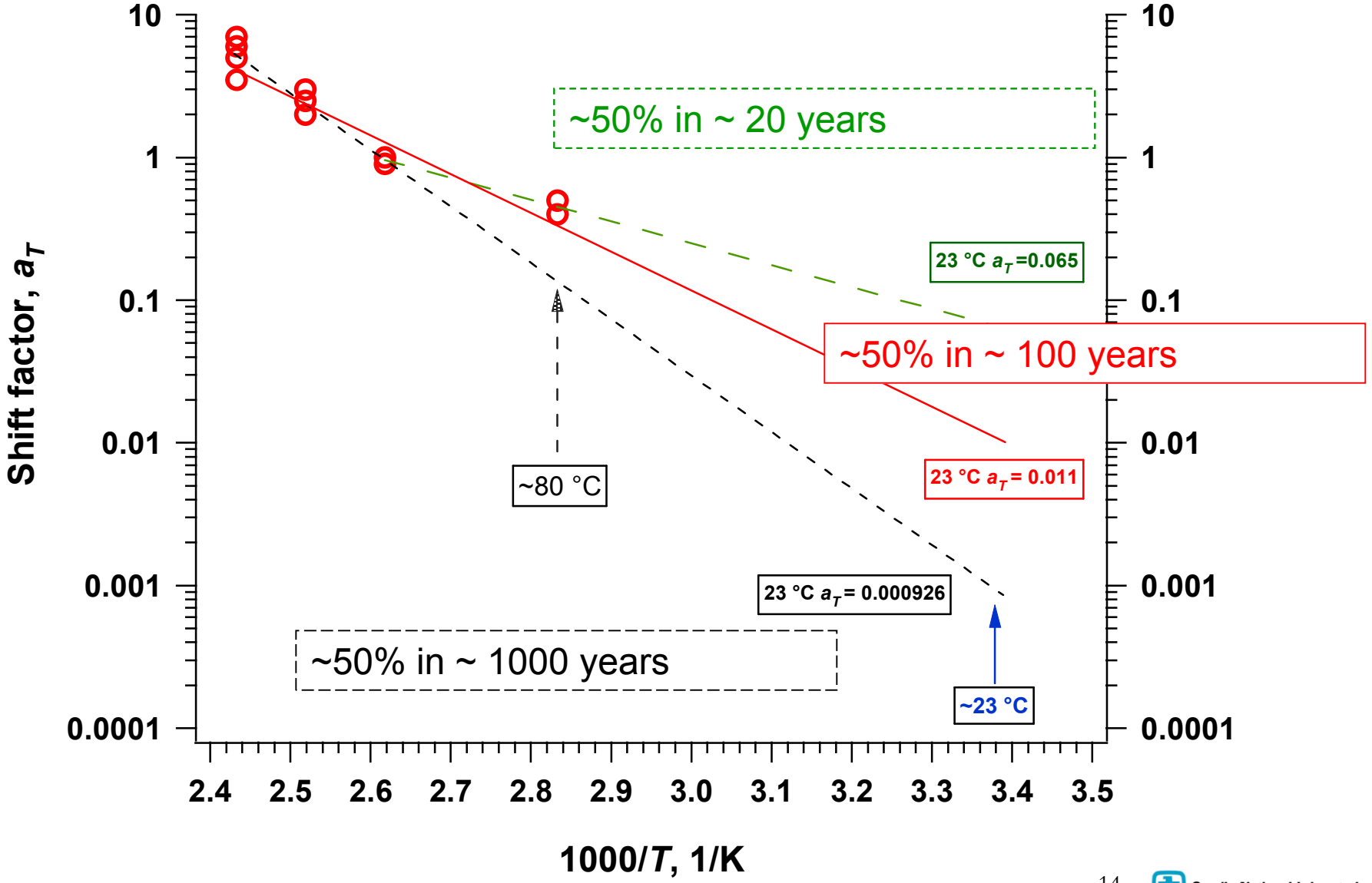
It is important to understand the degradation mechanism and select appropriate stress level



High T data are extrapolated to “use” conditions (room temperature)



How you extrapolate can influence lifetime predictions.



Two approaches to accelerated testing are used throughout industry

➢ Qualitative Accelerated Tests

- HALT tests
- HAST tests
- HASS tests

} Small sample size
Severe level of stress

Increase reliability (product improvement)
Qualify new designs
Design quantitative ALT

Reliability under normal use conditions

➢ Quantitative Accelerated Life Tests

- Controlled application of accelerated stress
- Produces acceleration factors (AF)
  - Usage rate acceleration (Time compression)
  - Overstress acceleration

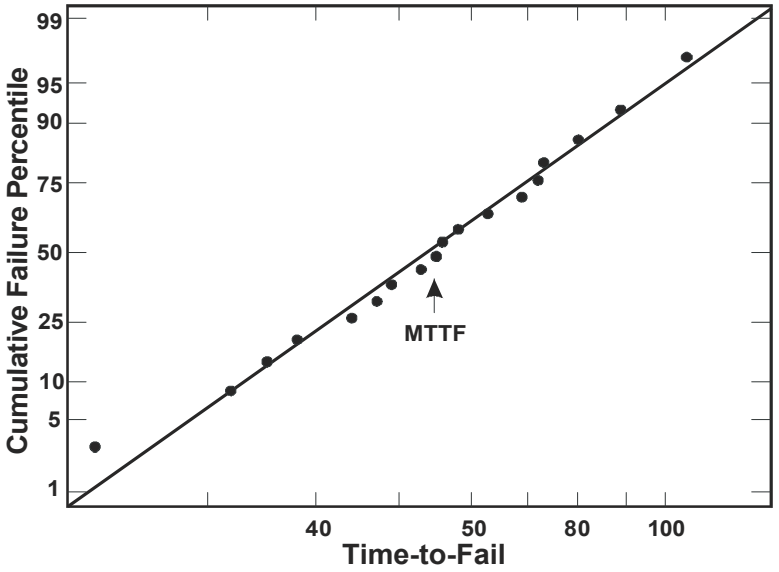
Used to determine TTF
Determine reliability

Long Time
Need degradation / failure mechanisms

The Goal of an ALT program is to produce acceleration factors

- **Often empirical correlations**
- **Limited root-cause analyses**

$$AF = \left(\frac{MTTF_{field}}{MTTF_{test}} \right)$$

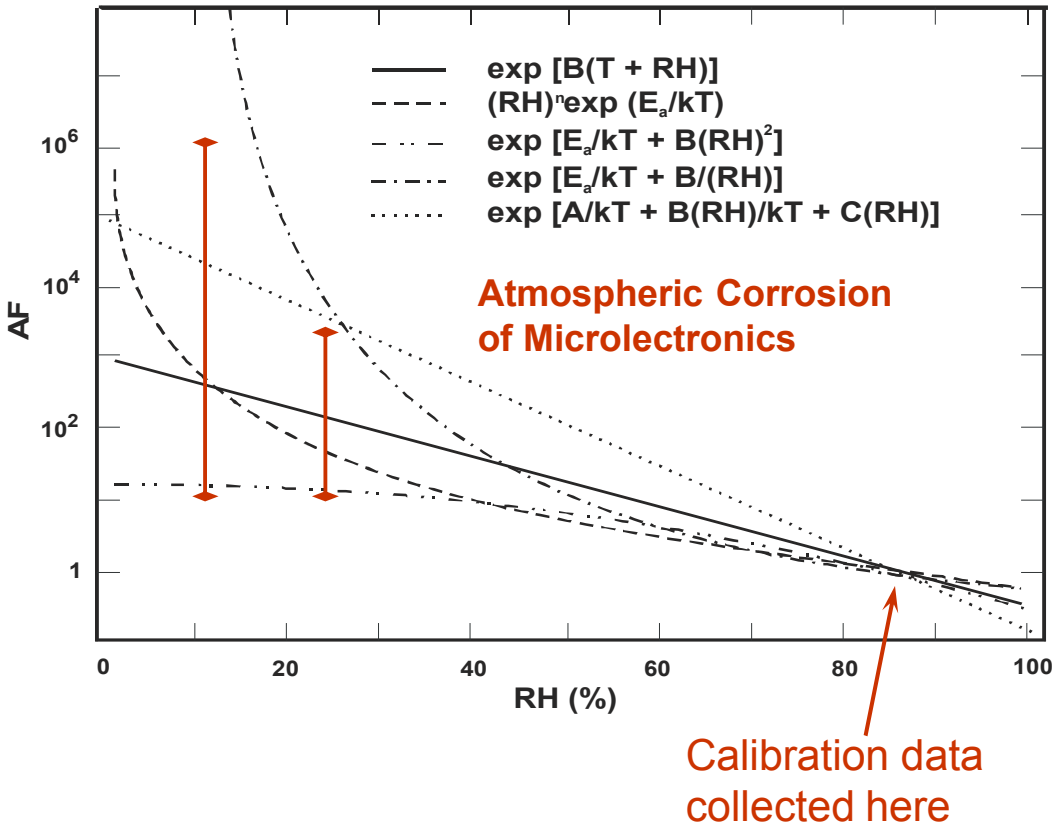


$$AF = \exp\left[\frac{E_a}{k} \left(\frac{1}{T_o} - \frac{1}{T} \right) \right] \left(\frac{RH}{RH_o} \right)^n \left(\frac{a+bV}{a+bV_o} \right)$$

ALT must capture valid degradation / failure mechanisms

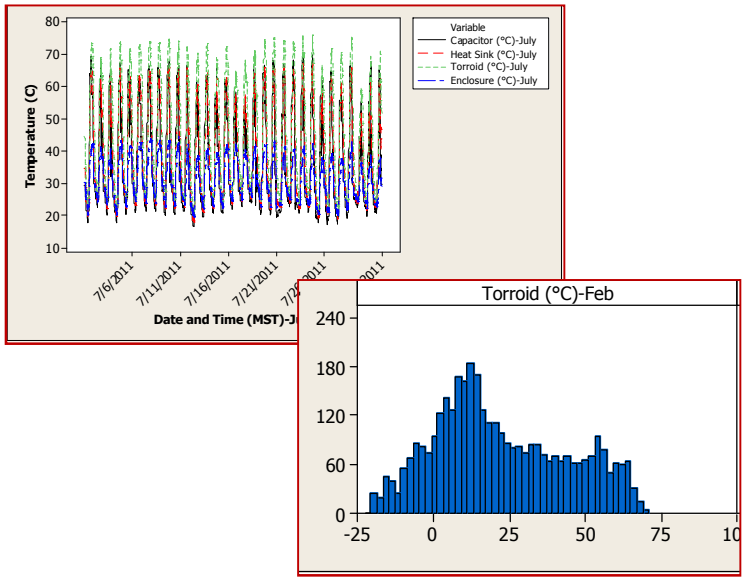
Example:

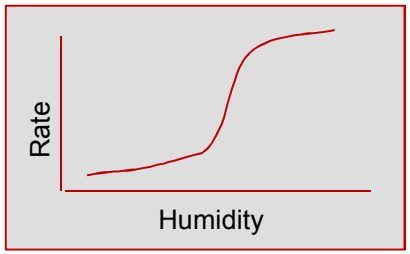
- Five recognized models for corrosion in micro-electronics
- All agree at 85%RH
- Disagreement at 10%-30% prevents uniform application of either model



Acceleration factors depend on the stress characteristics

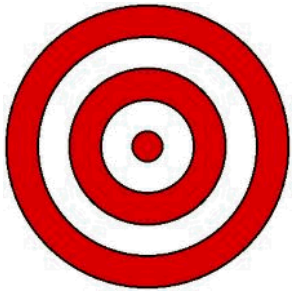
- Thermal (Arrhenius)
  - Activation energy
  - Verify no mechanism change
  - Bin damage by time at temperature
- ΔT
  - Linear (time compressions),
  - Increased temperature range
  - Frequency analysis (rainflow counting)
- Voltage
  - Linear (must understand relationship)
- Humidity
  - Tends to be complex (adsorbed water)





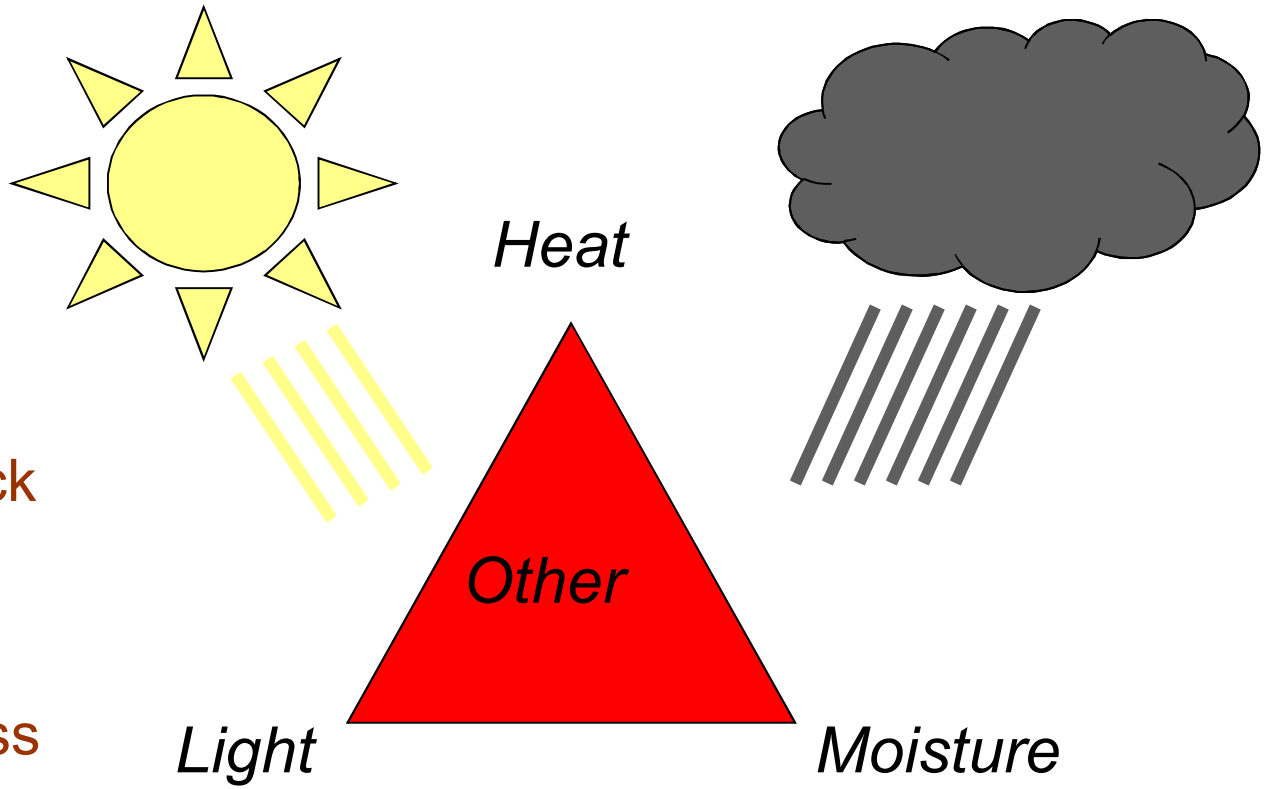
Issues with ALT

- Unknown failure mechanisms
- Unknown / variable use environment
- Changing mechanisms as function of environmental stress
- Difficult to control and characterize defects
- Long duration experiments
- Evolving / improving technology

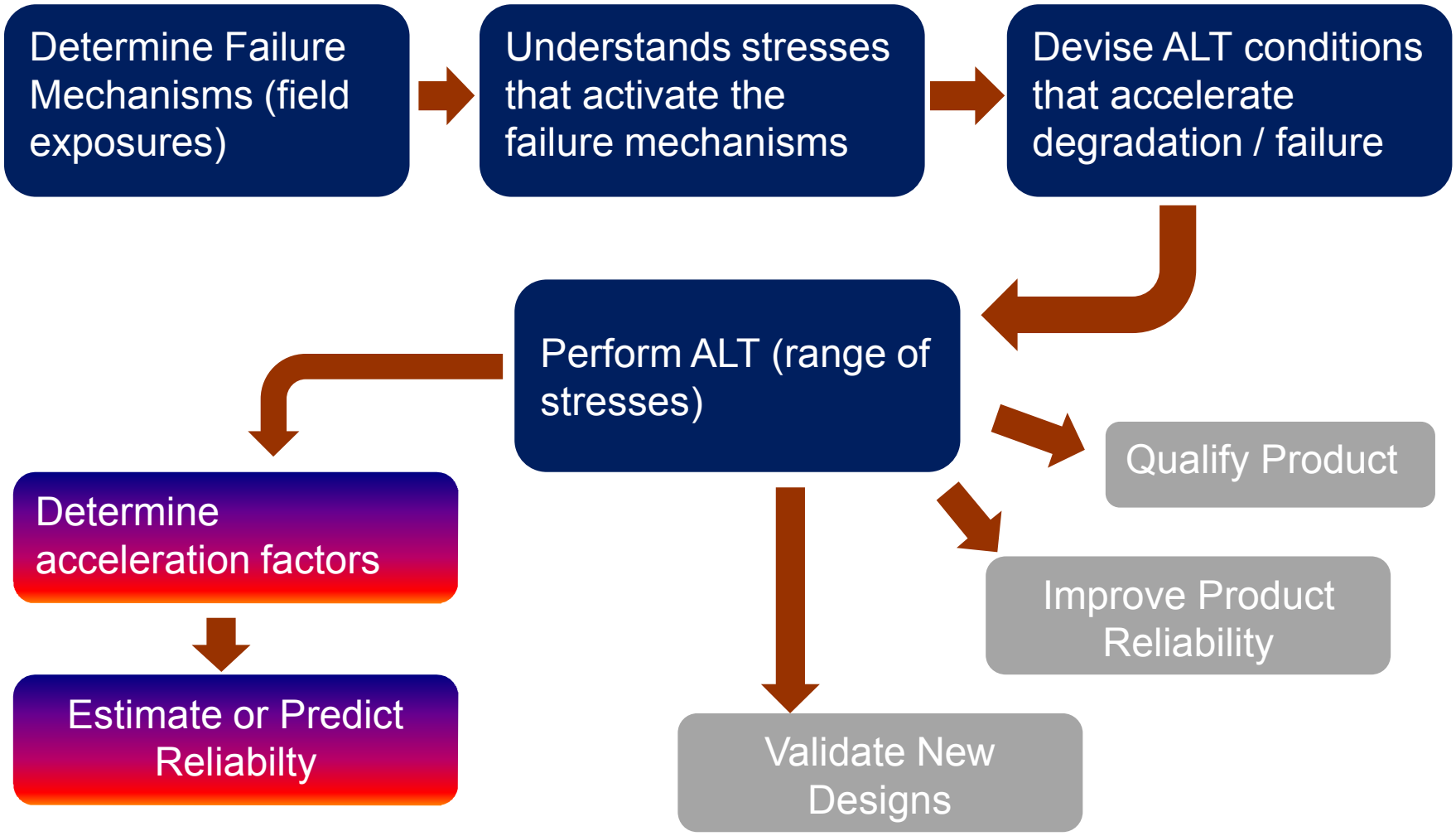


What are the likely stresses that lead to Inverter Failure?

- Voltage
- Temperature
- Thermal cycling
- Thermal Shock
- Vibration
- Mechanical Shock
- Humidity
- Contamination
- Mechanical Stress
- ???
- ???

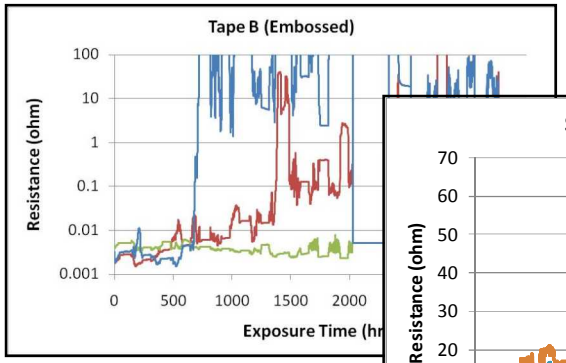


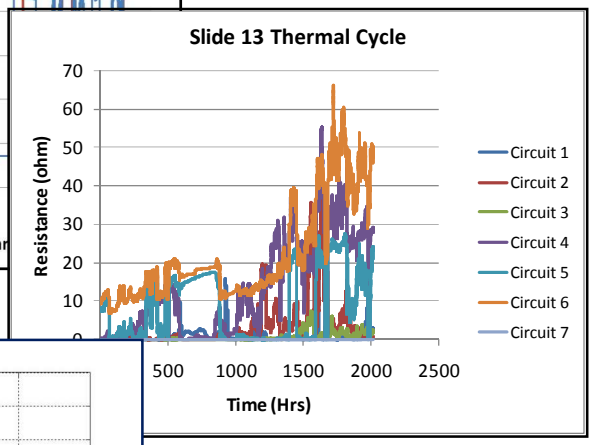
How do we apply ALT to predicting end-of-life (wear out)?

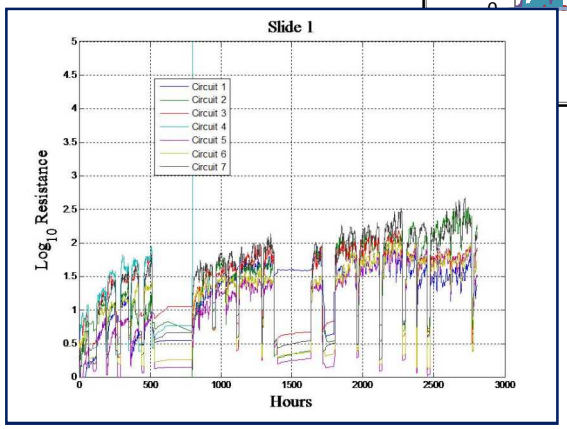


Analysis of metal foil tape degradation

Generate ALT data



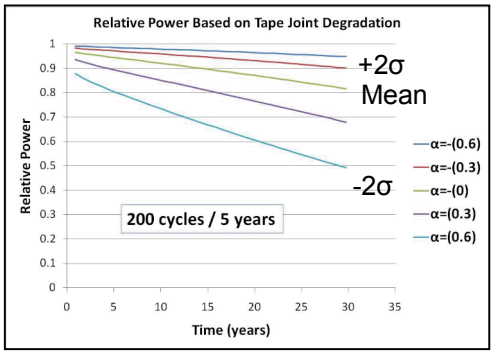




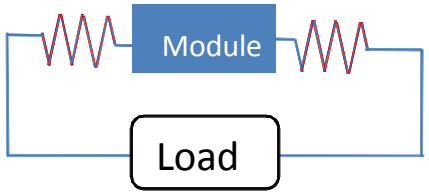
Develop "acceleration factors"

$$R = 10^{(0.028(\sqrt{t})+\alpha)}$$

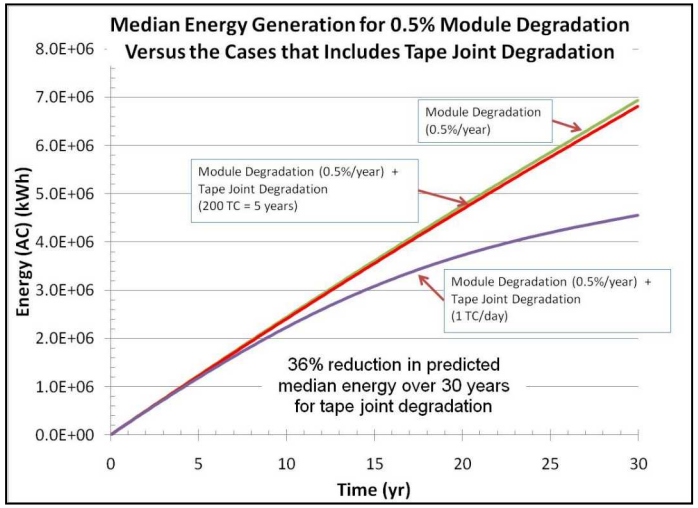
Apply acceleration factors to field



Determine performance effect



$$E = I \times R$$
$$P = I \times V = I^2 \times R$$



Summary

Accurate prediction of reliability is complex

- Requires understanding of degradation processes
- Data Driven
  - Field data
  - Accelerated testing
- Effect on performance (what is failure?)
- Includes uncertainty