

Corrosion and Accelerated Testing

Rob Sorensen

505-844-5558

nrsoren@sandia.gov

Sandia National Laboratories



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.

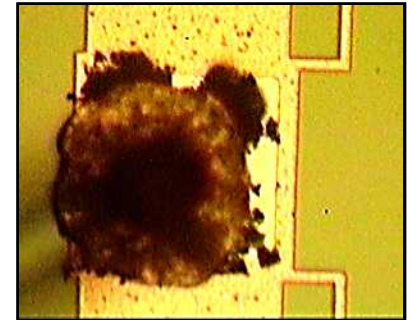
What is corrosion?

Environmental degradation of materials

➤ Aqueous (general & localized attack)

- electrochemical
- oxidation / reduction

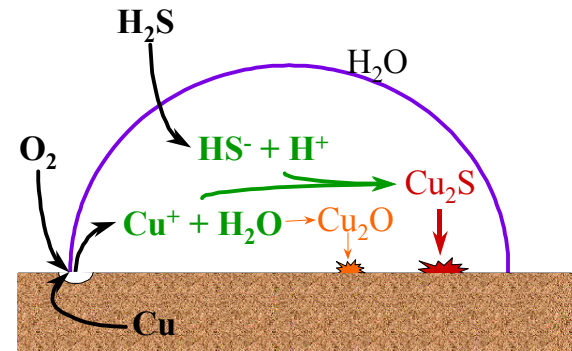
Processing



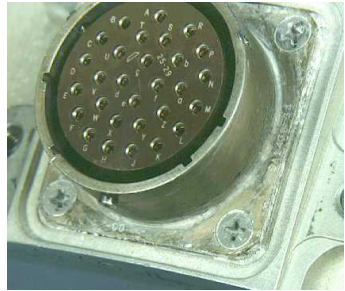
➤ Atmospheric

- gas-metal reaction (slow)
- condensed phase electrochemical
- pollutant gasses (ppt levels of H_2S , NO_2 , Cl_2 ...)

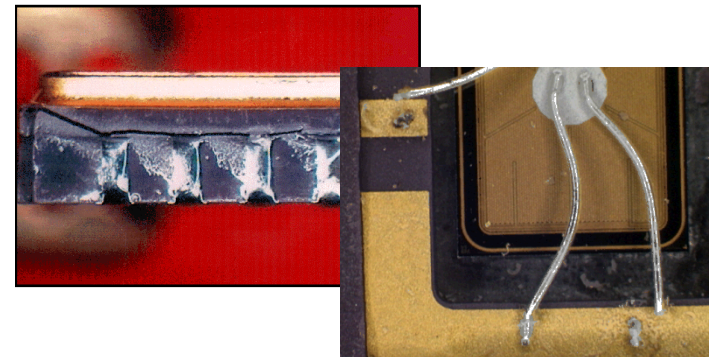
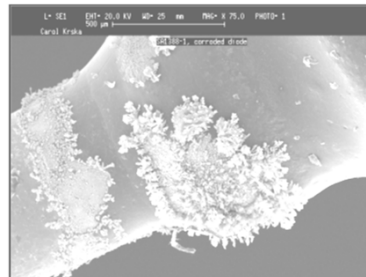
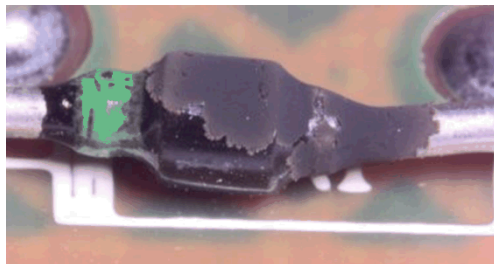
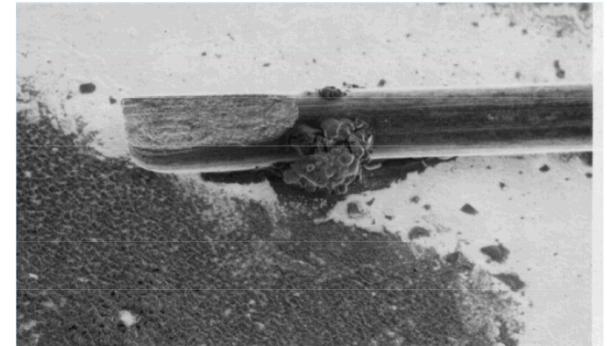
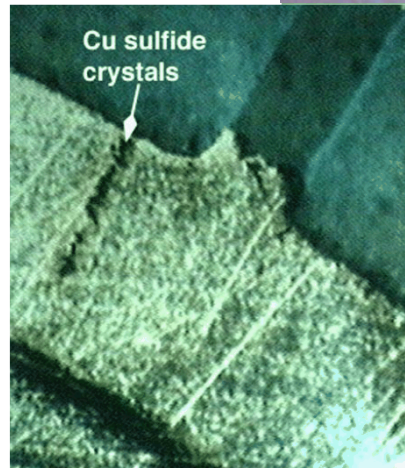
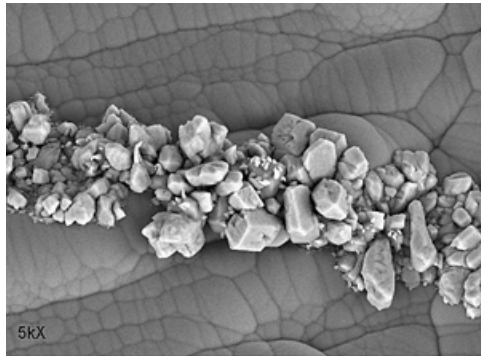
Use



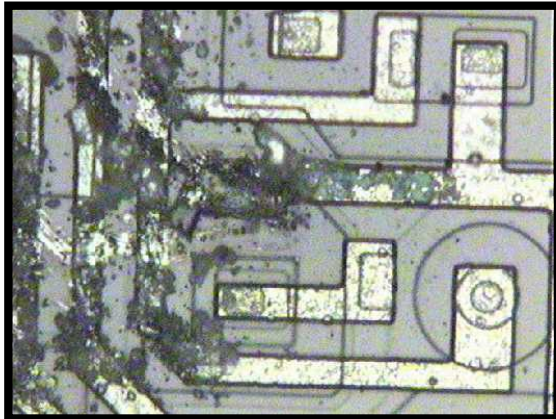
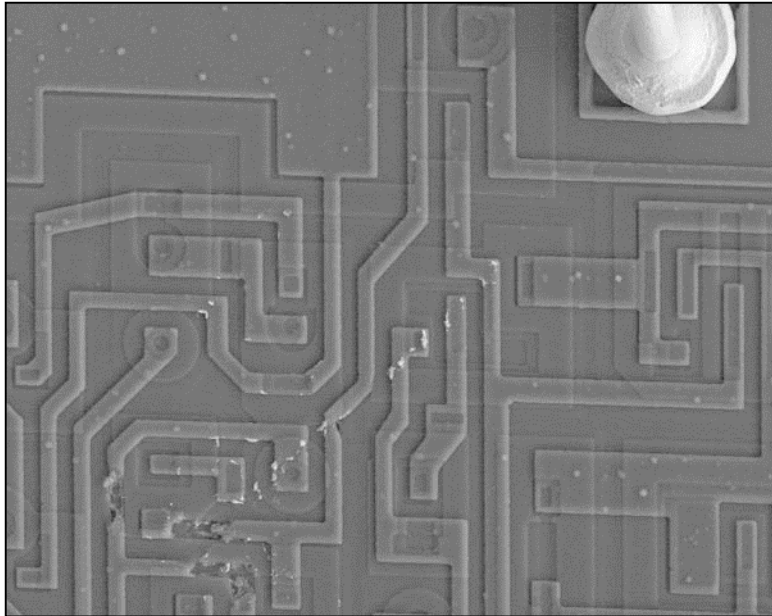
Corrosion normally occurs due to defects or unexpected environments



Cruise missile fuel line

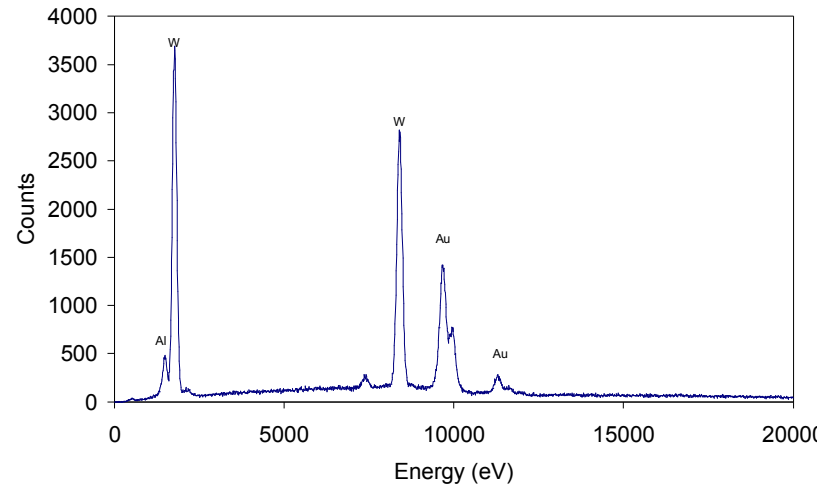


A plastic encapsulated IC failed after 5 years in dormant storage.



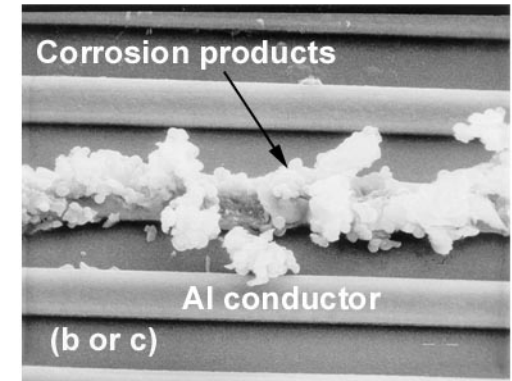
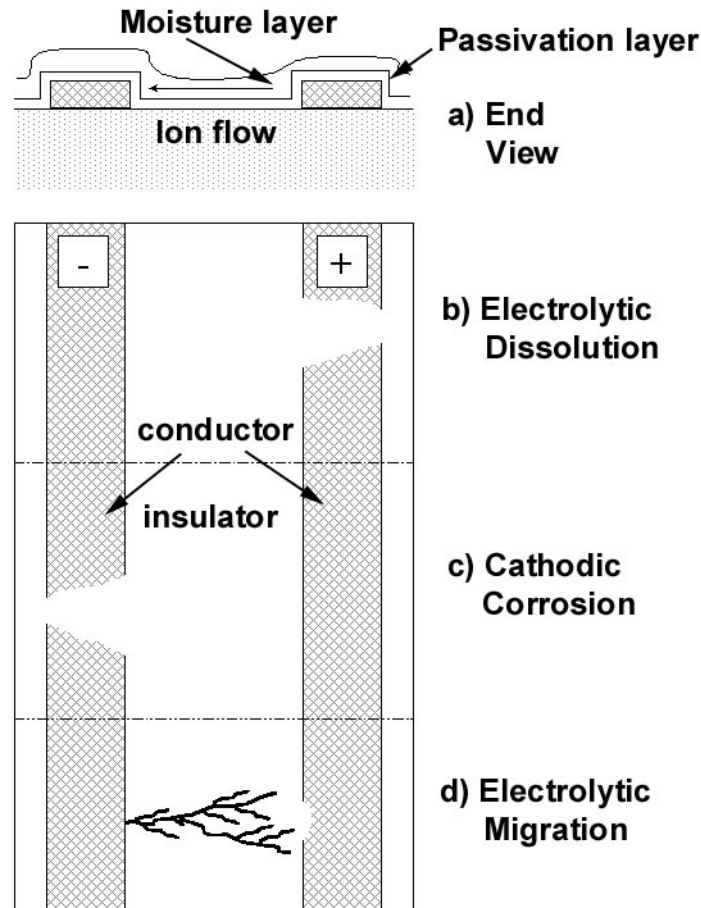
Defects:

- Damaged passivation
- Au (galvanic couple)



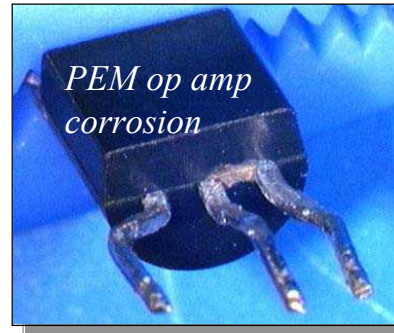
Several non-traditional corrosion mechanisms exist in microelectronics that involve electrical bias

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



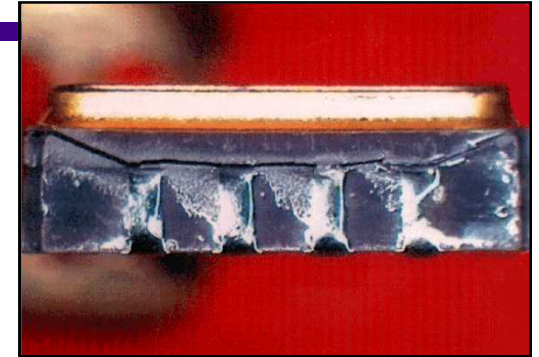
Conditions required for electrolytic migration

- 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

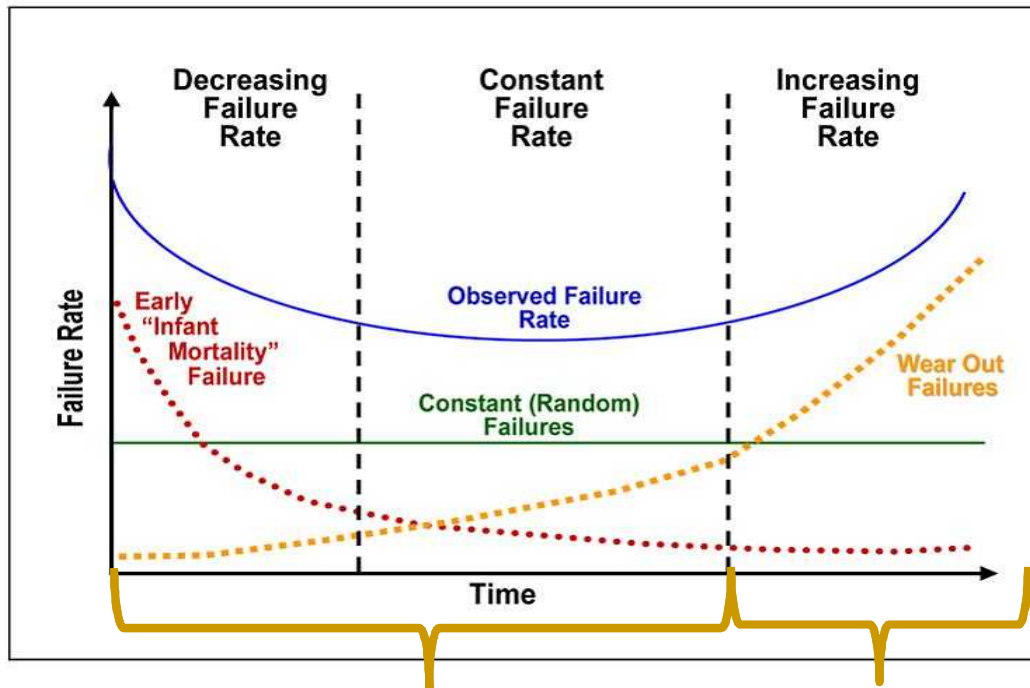
- **Breach in hermetic packaging in CHP**
- **Use of encapsulants in PEMs with high water permeability**
- **Specific unintended exposures (e.g., military)**
 - **high T, RH, [Cl⁻] possible**



Materials Degradation Affects Reliability

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

Reliability  Cost



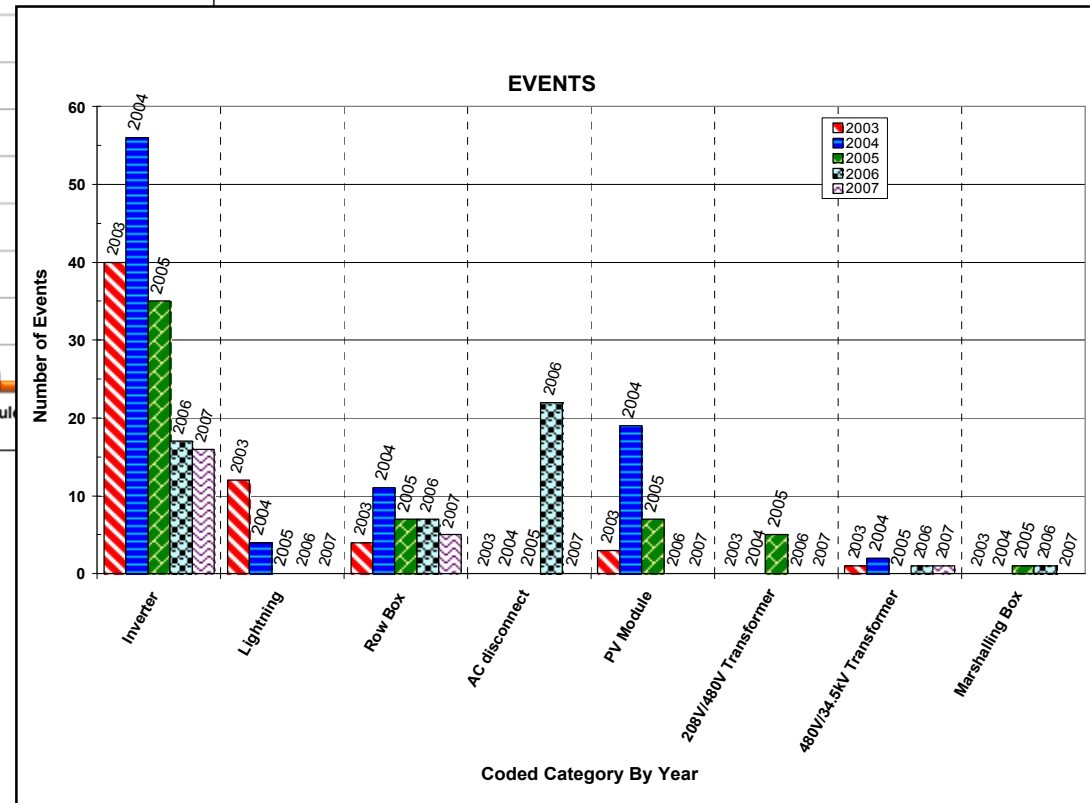
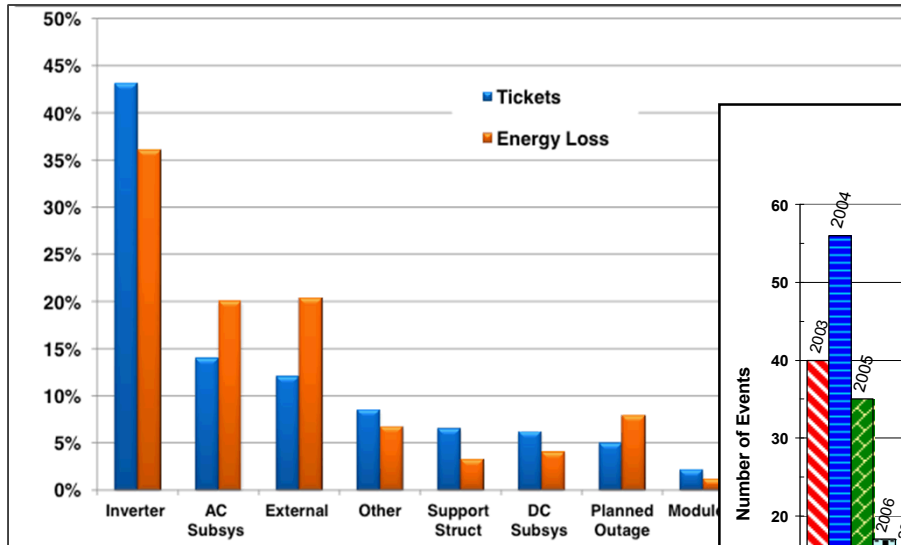
Lab and Field Data

Accelerated Tests

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

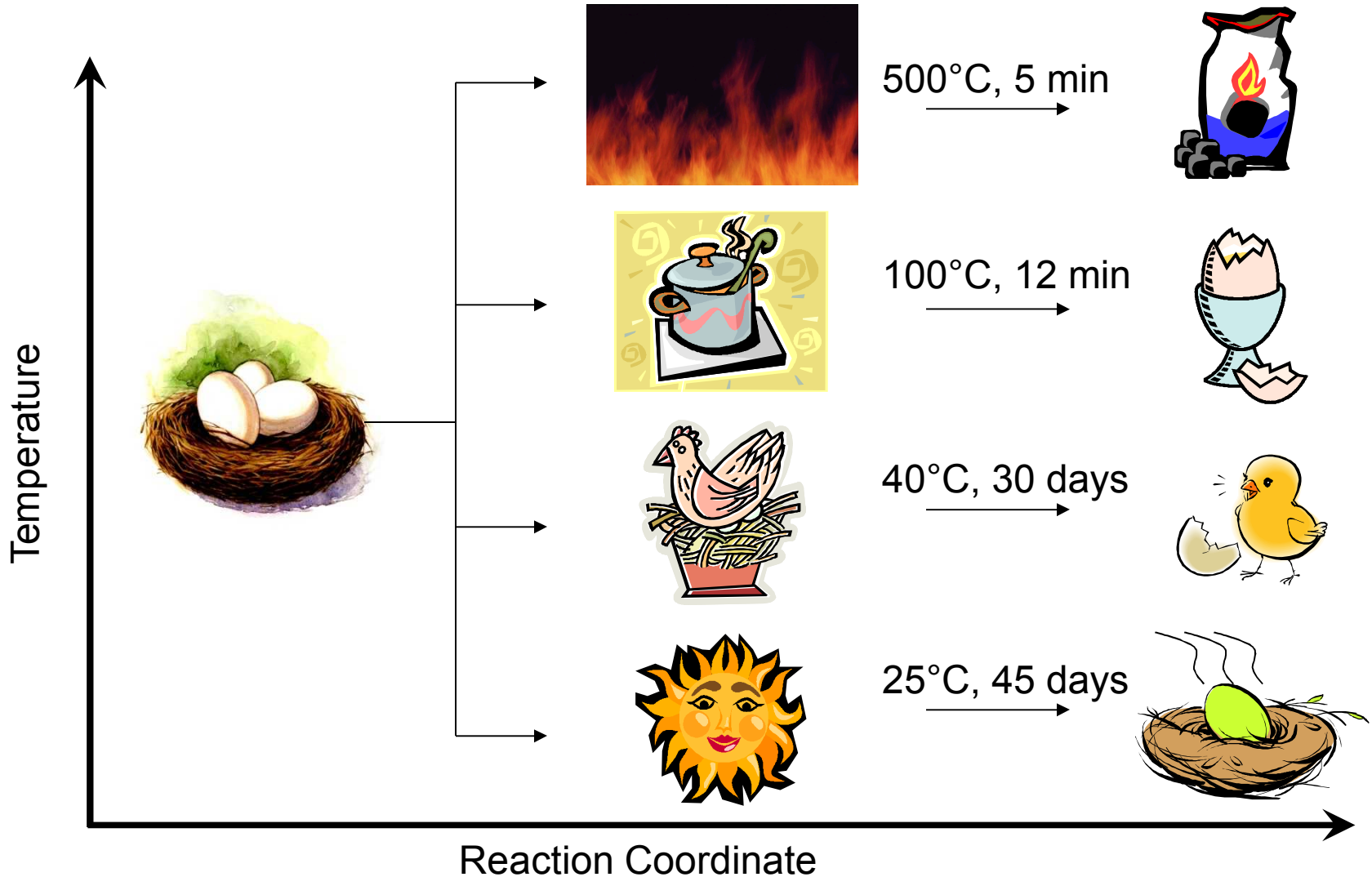
Failure Modes for Crystalline Silicon

(John Wolgemuth – BP Solar)

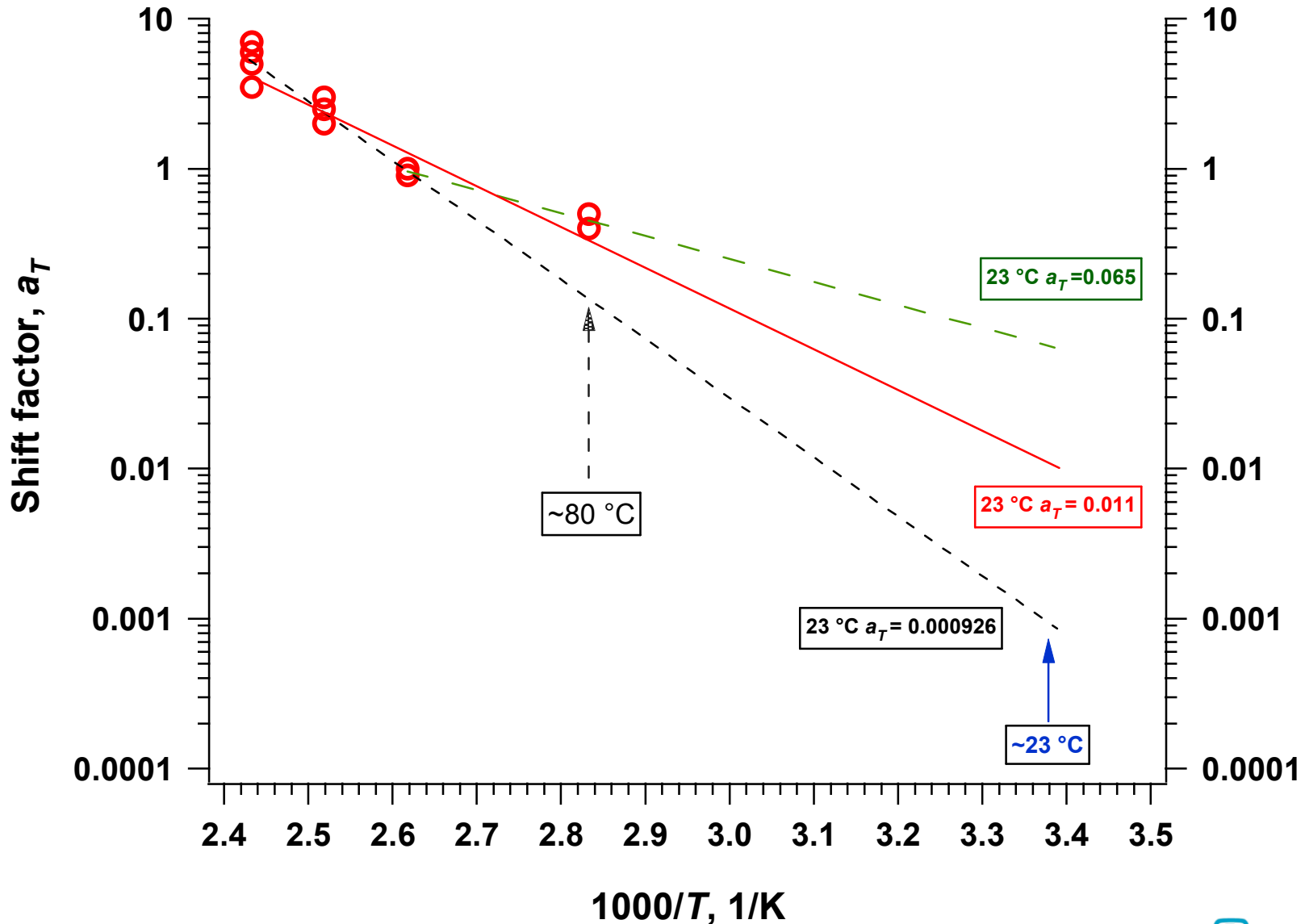
- Broken interconnects
- Broken Cells
- Corrosion
- Delamination and/or loss of elastic properties
- Encapsulant discoloration
- Solder bond failures
- Broken glass
- Hot Spots
- Ground faults
- Junction box and module connection failures
- Structural failures

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

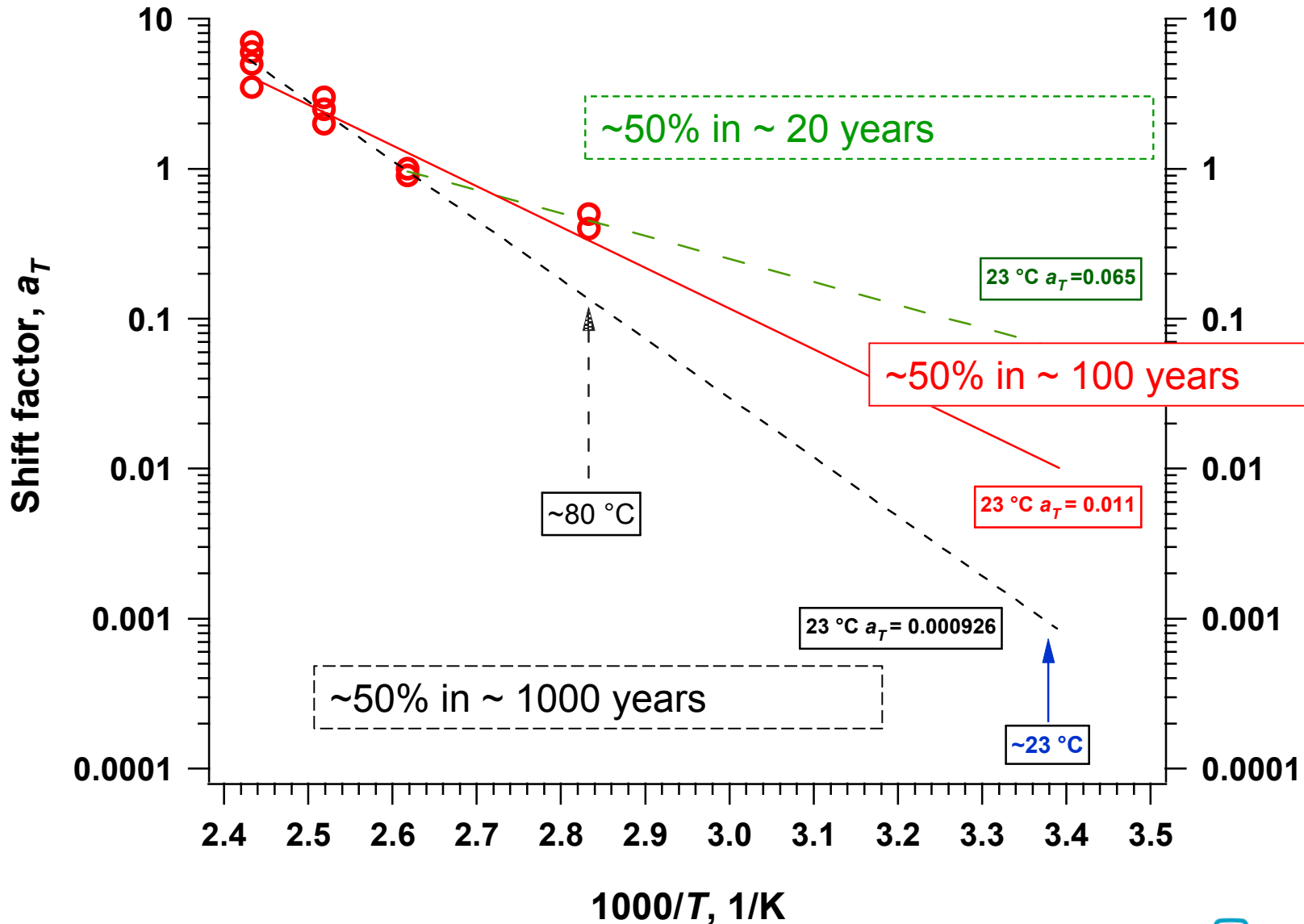
It is important to understand the degradation mechanism and select appropriate stress level



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

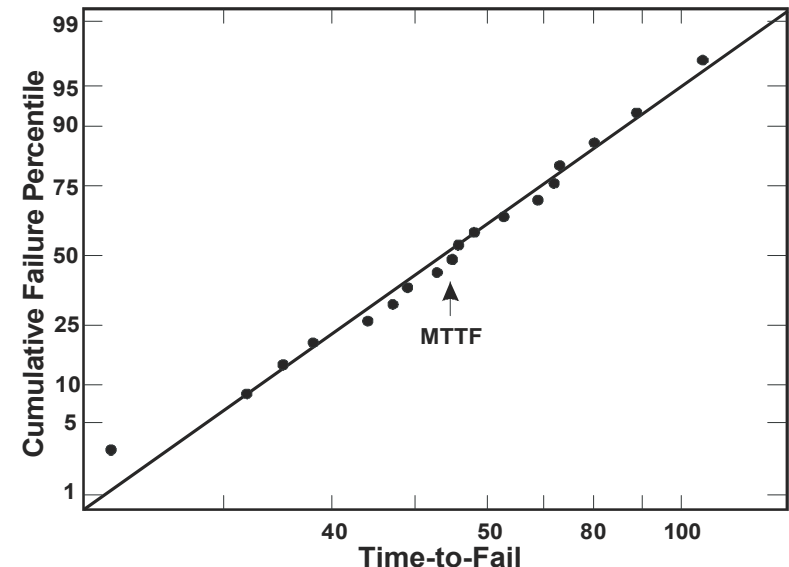
Used to determine TTF
Determine reliability

Long Time
Need degradation / failure
mechanisms

The Goal of an ALT program is to produce acceleration factors

- Often empirical correlations
- Limited root-cause analyses

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

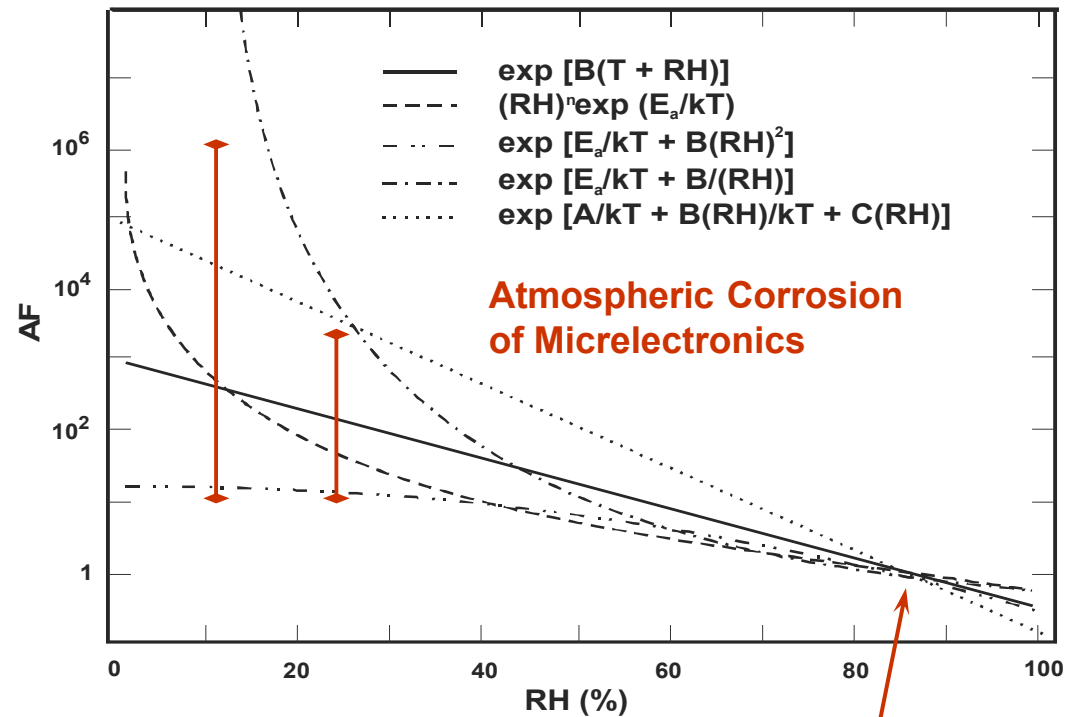


$$AF = \exp \left[\frac{E_a}{k} \left(\frac{1}{T_0} - \frac{1}{T} \right) \right] \left(\frac{RH}{RH_0} \right)^n \left(\frac{a+bV}{a+bV_0} \right)$$

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% prevent 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

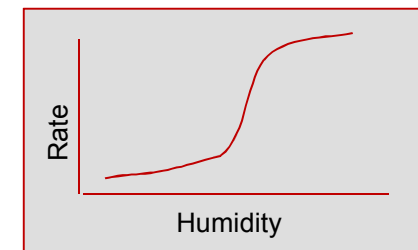
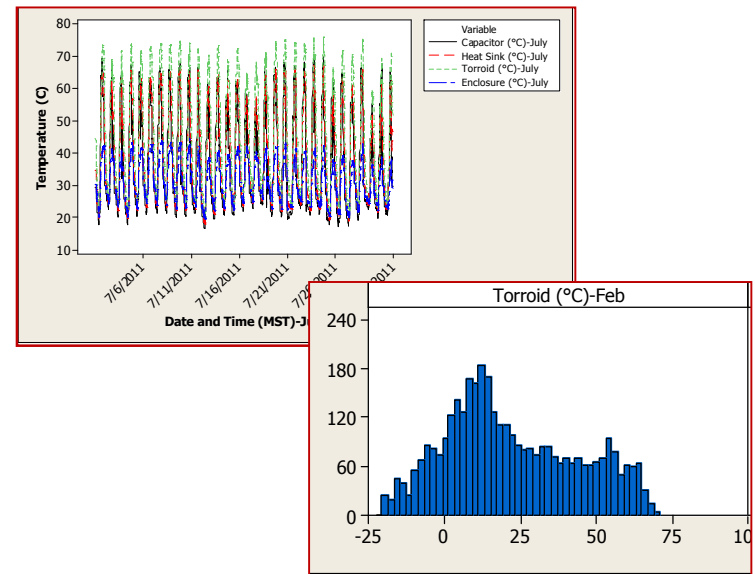
- Linear (time compressions),
- Increased temperature range
- Frequency analysis (rainflow counting)

➤ Voltage

- Linear (must understand relationship)

➤ Humidity

- Tends to be complex (adsorbed water)



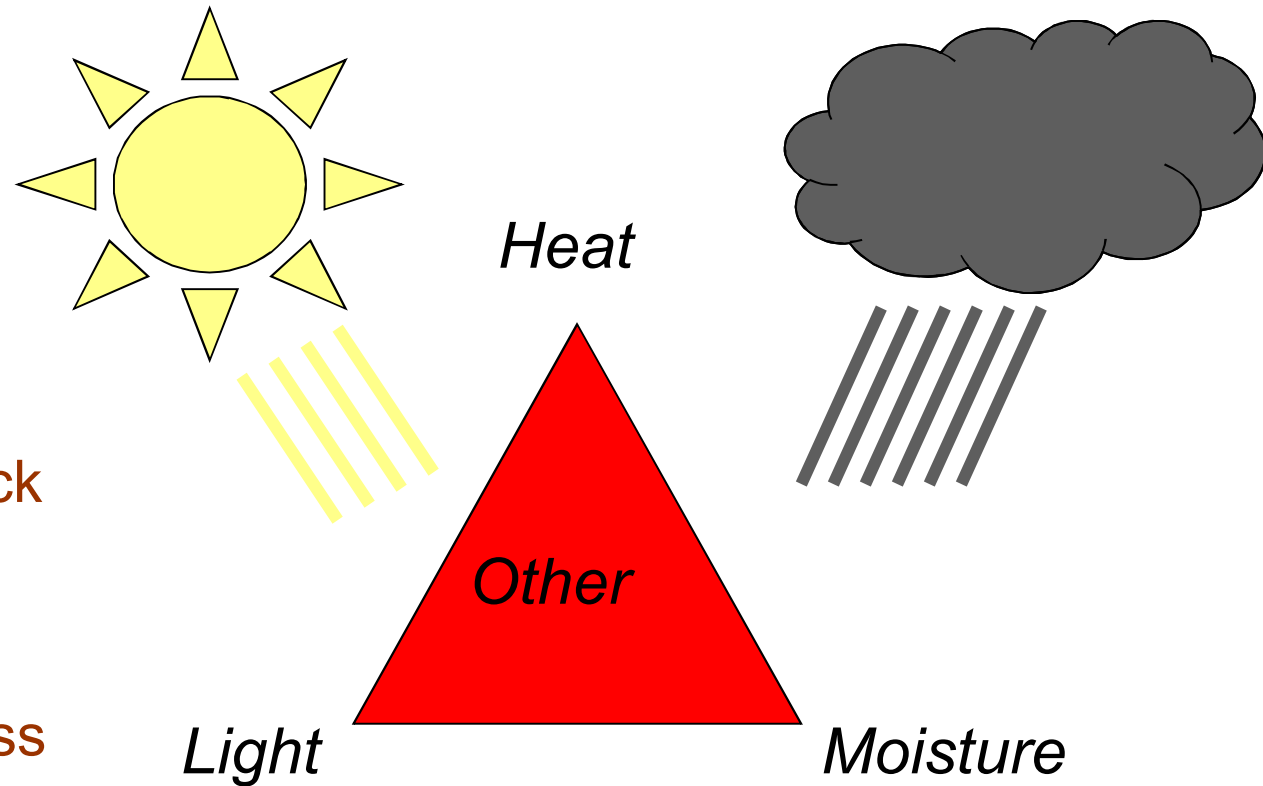
Issues with ALT

- 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

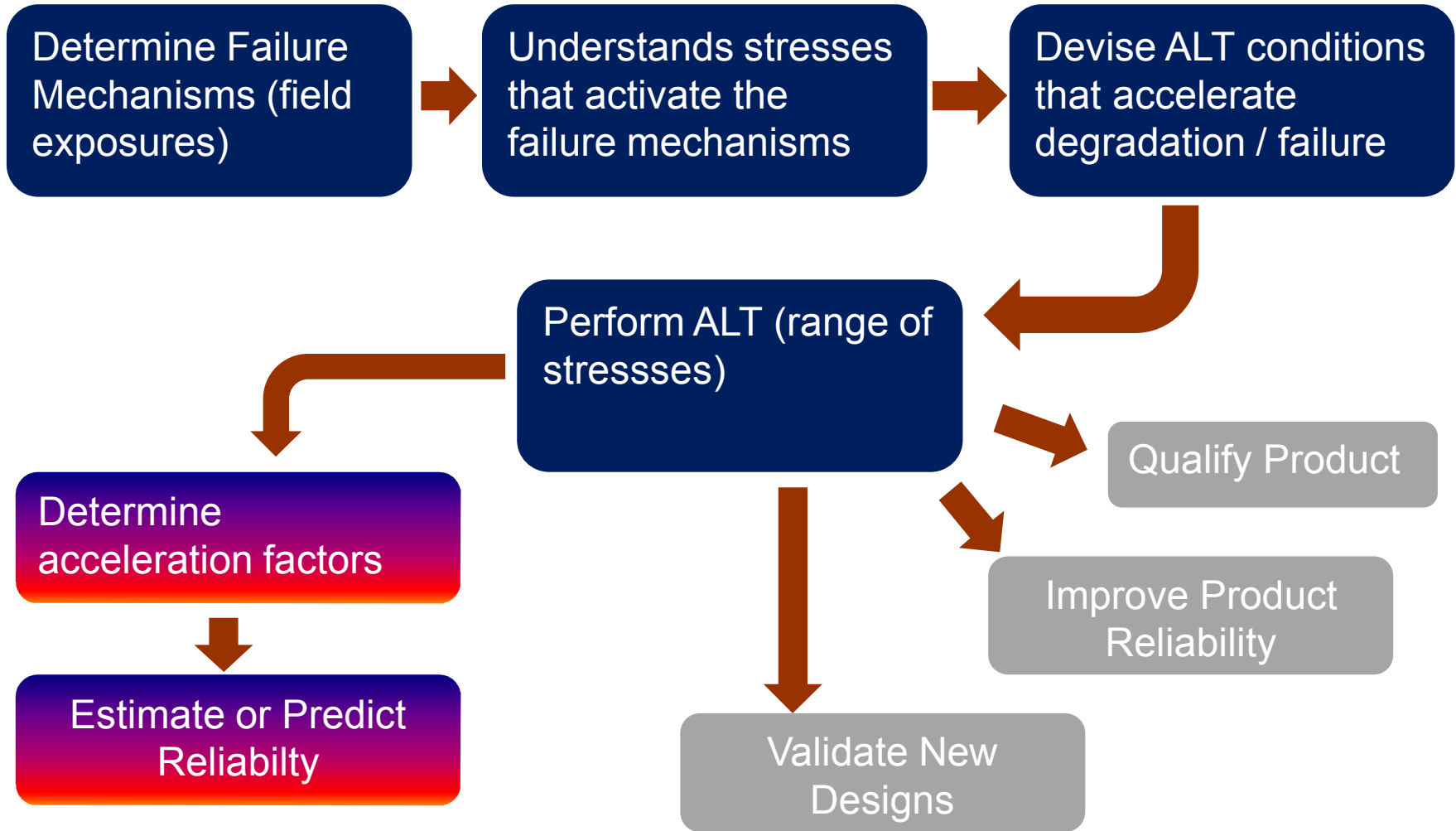


What are the likely stresses that lead to Inverter Failure?

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

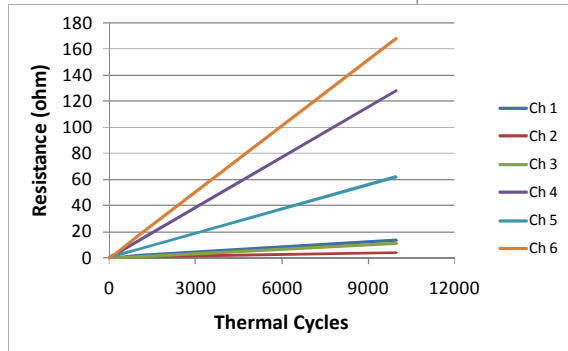
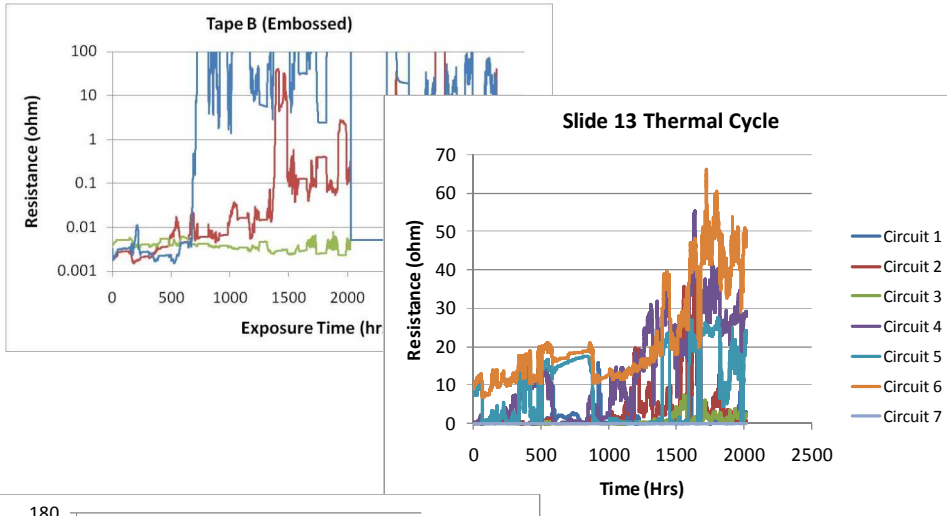


How do we apply ALT to predicting end-of-life (wear out)?

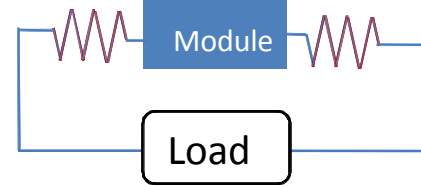


Analysis of metal foil tape degradation

Generate ALT data



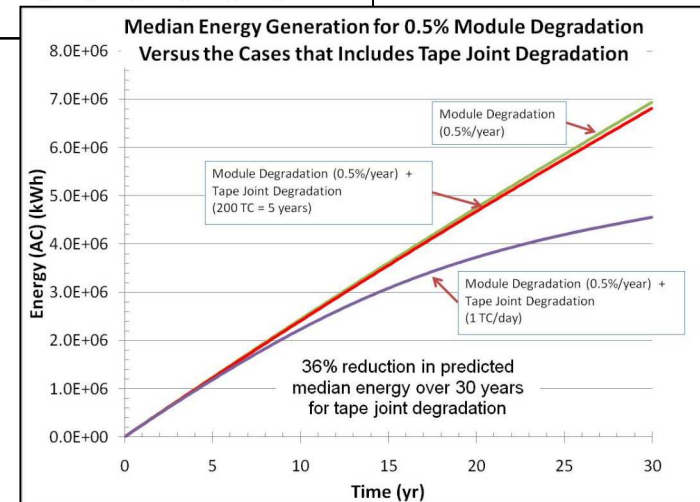
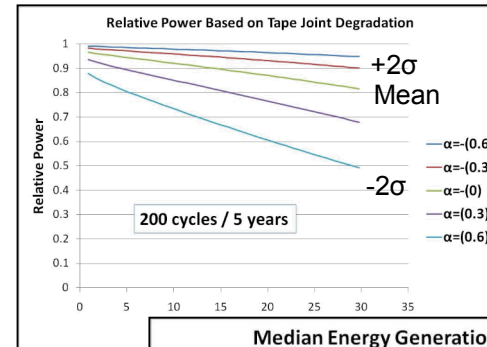
Determine performance effect



$$E = I \times R$$

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

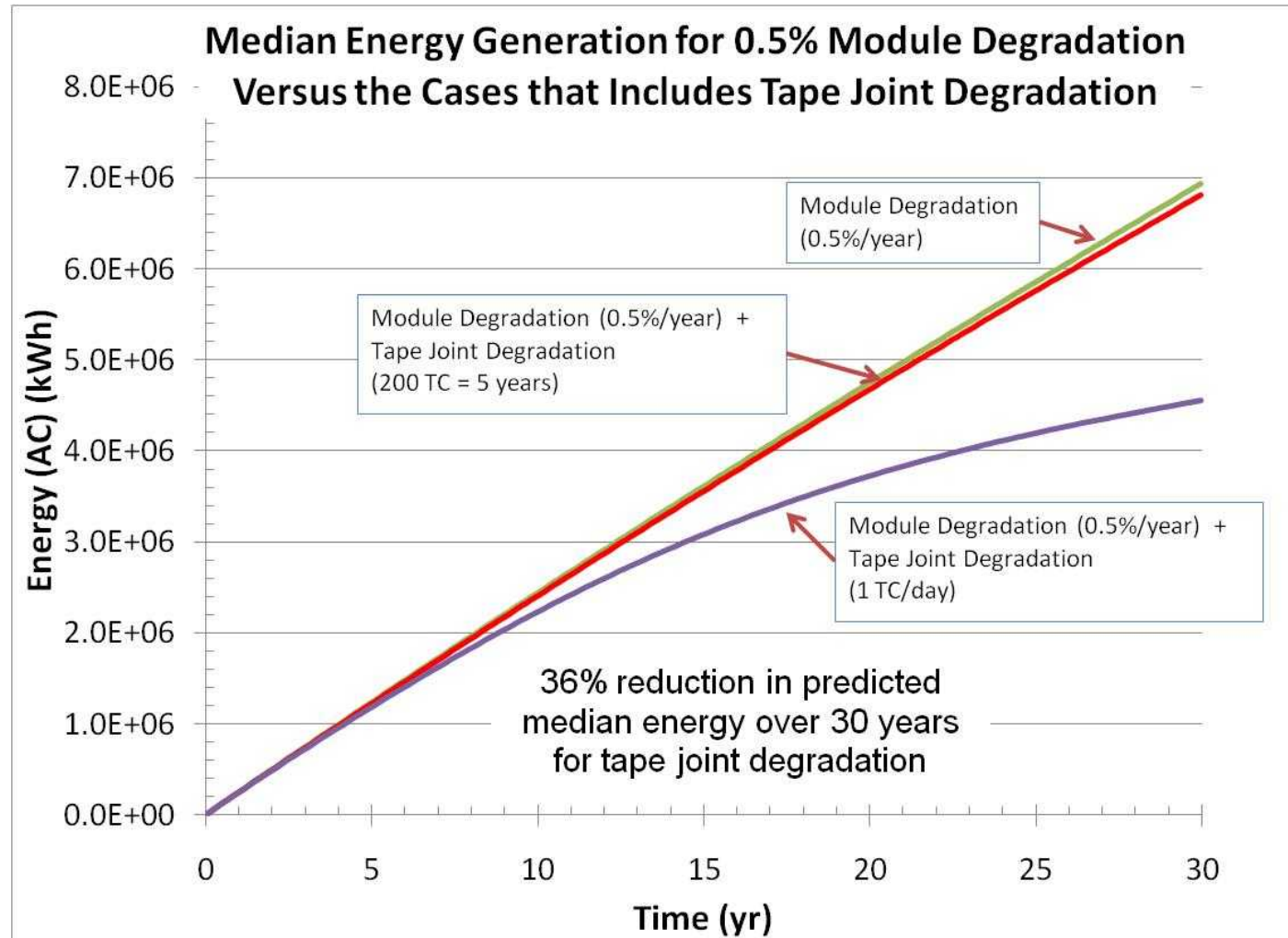
Apply acceleration factors to field



Develop "acceleration factors"

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

Use the ALT data to predict long-term performance degradation (wear-out???)



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