Accelerated Life Testing

Rob Sorensen
Sandia National Labs
nrsoren@sandia.gov
505-844-5558

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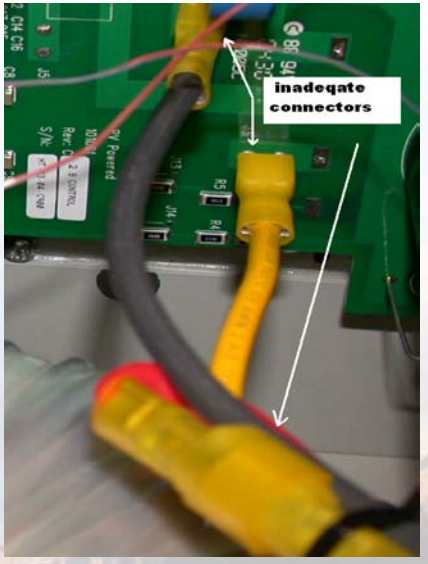
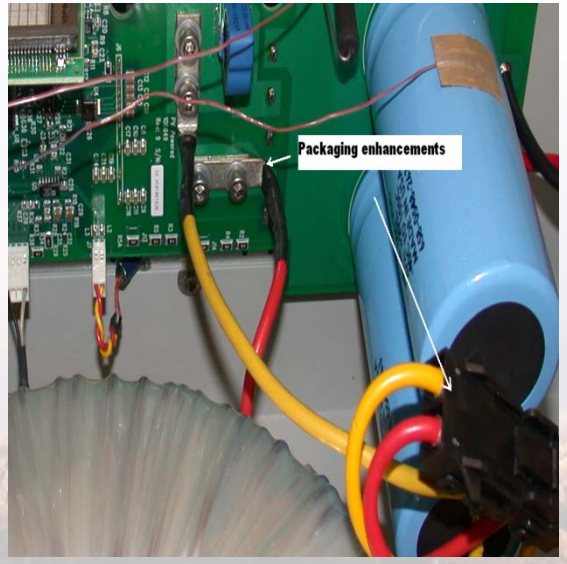
Accelerated Aging for Inverters

- No PV specific industry standard exists
- HALT testing is spotty; independently applied
- Separate needs identified for residential and commercial scale inverters
- Failure modes identified but not in a uniform program applicable across the industry
- System predictive models will require inputs for inverters





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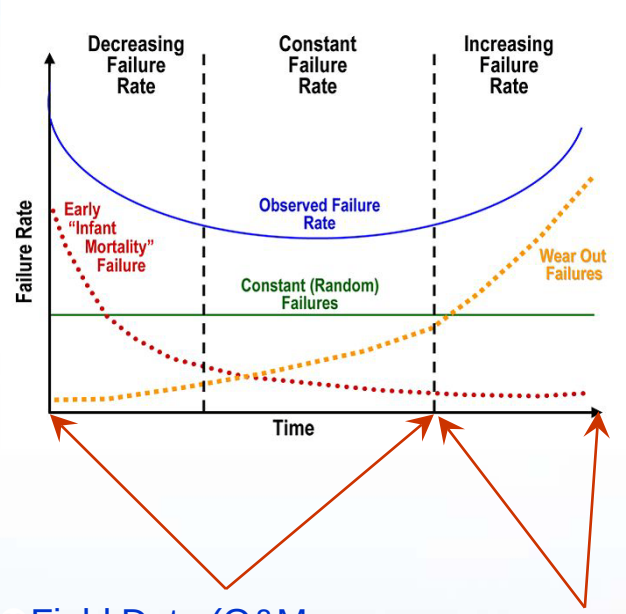
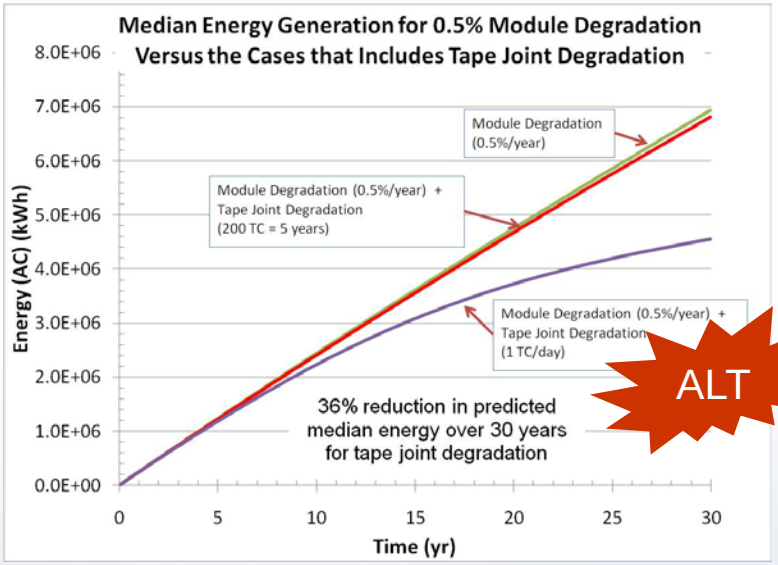
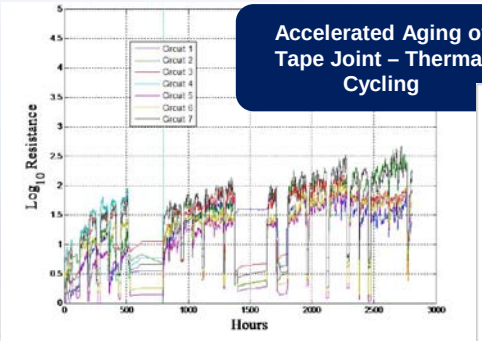
Laboratory testing provides vital information for PV system reliability

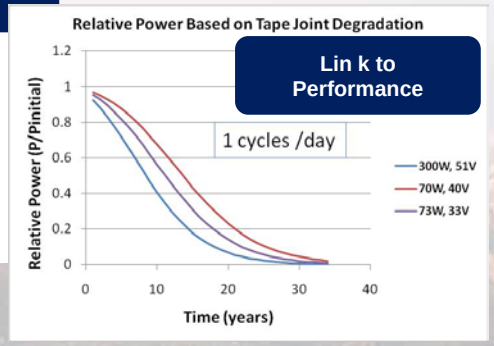


- Field Data (O&M, Failures, …)
- Accelerated Testing / Lab Tests

System performance model must include wear out (end of life) information







Acceleration Factors

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What is ALT & why?

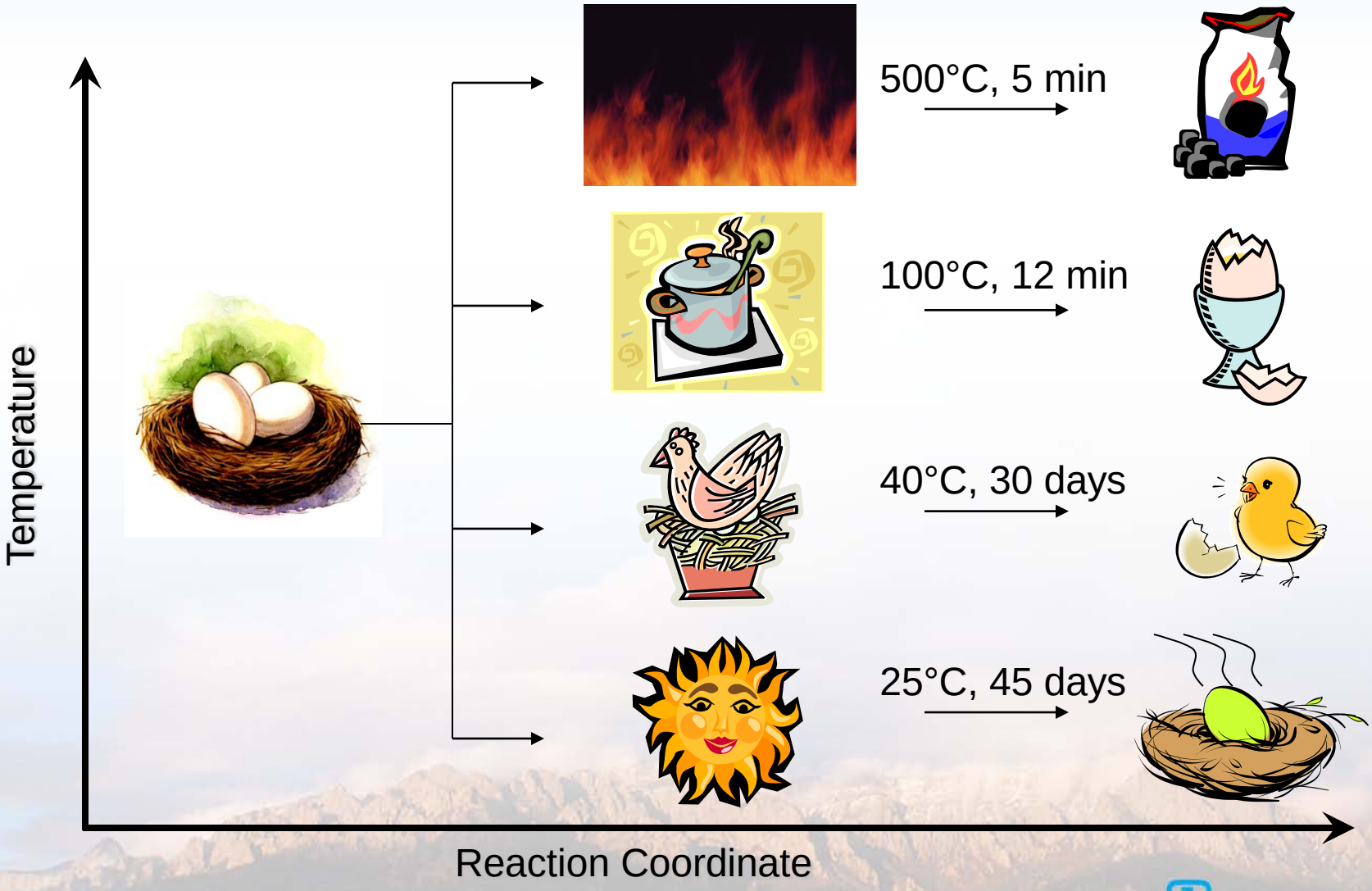
What?

- Component life tests
- High stresses
  - Single or combined
  - Activate “appropriate” failure modes
  - Measureable
- Failure analysis

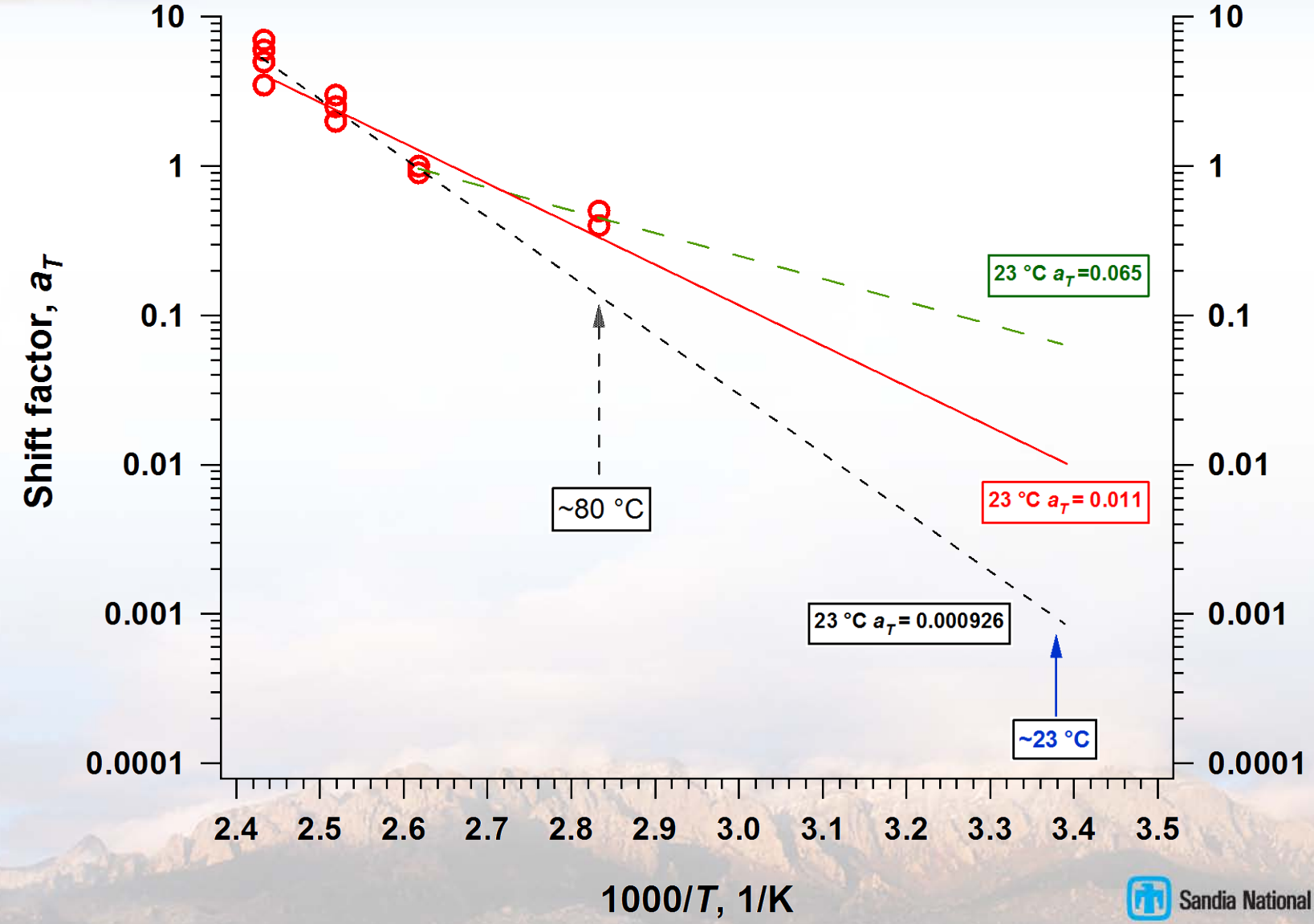
Why?

- Time
- Full system is expensive and complicated

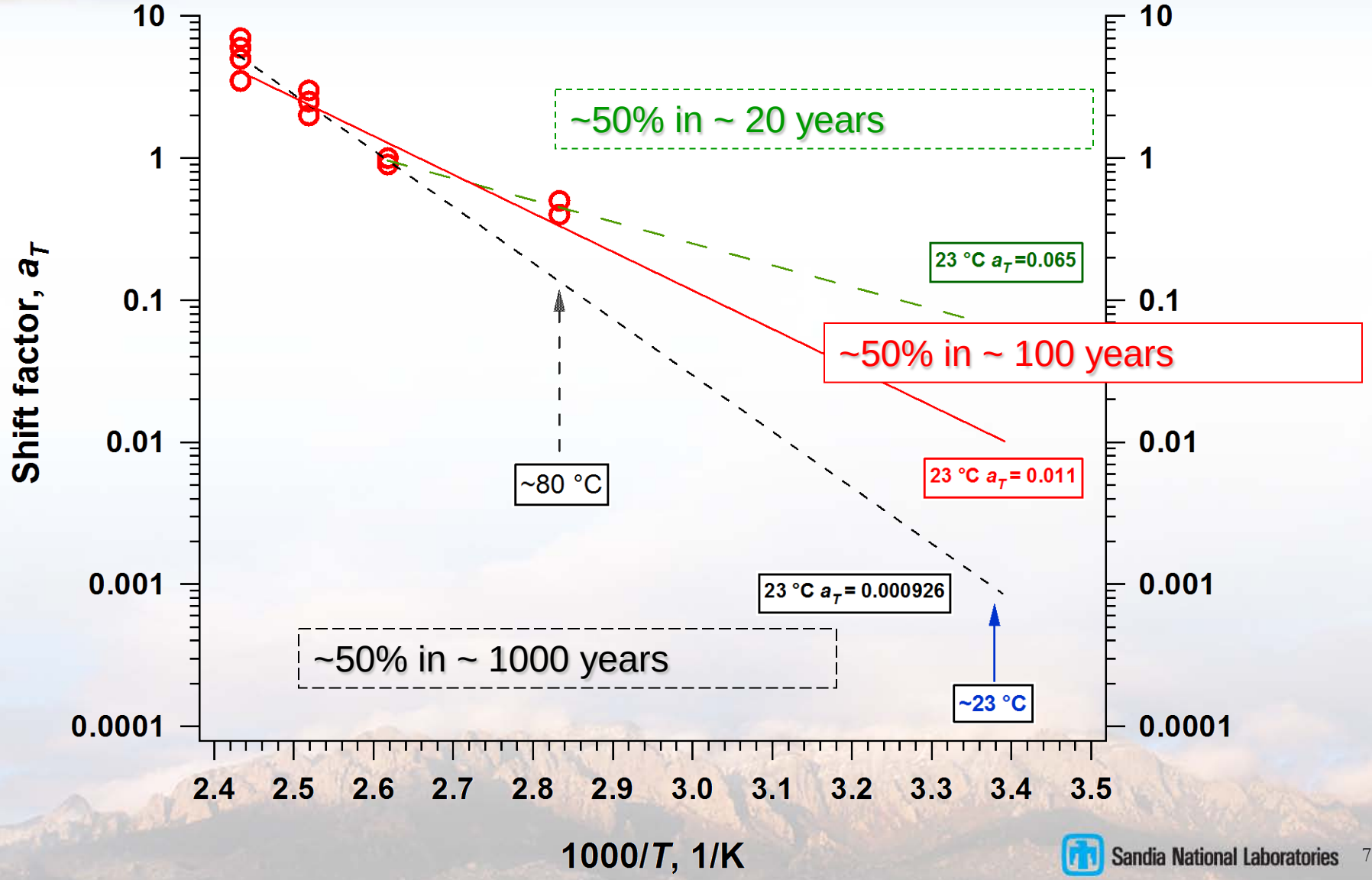
‘Accelerated Aging’



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

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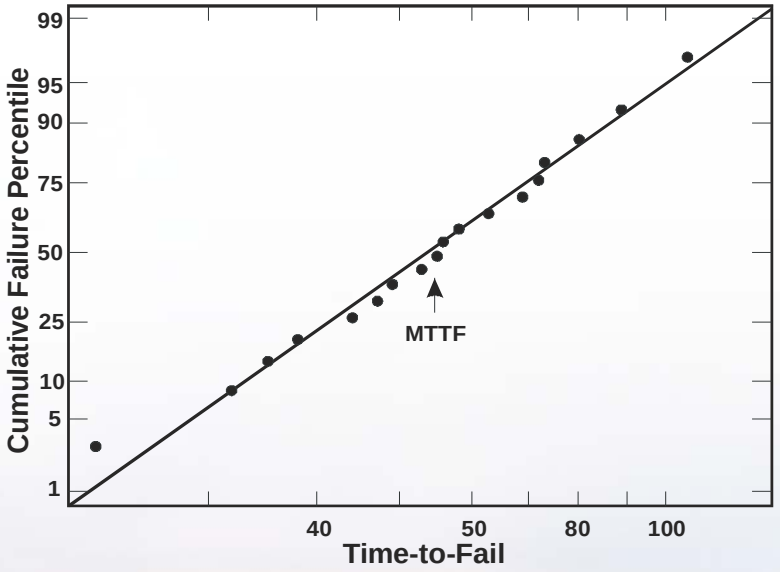
The Goal of an ALT program is to produce acceleration factors

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

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



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

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Empirical relationships may not cut it!

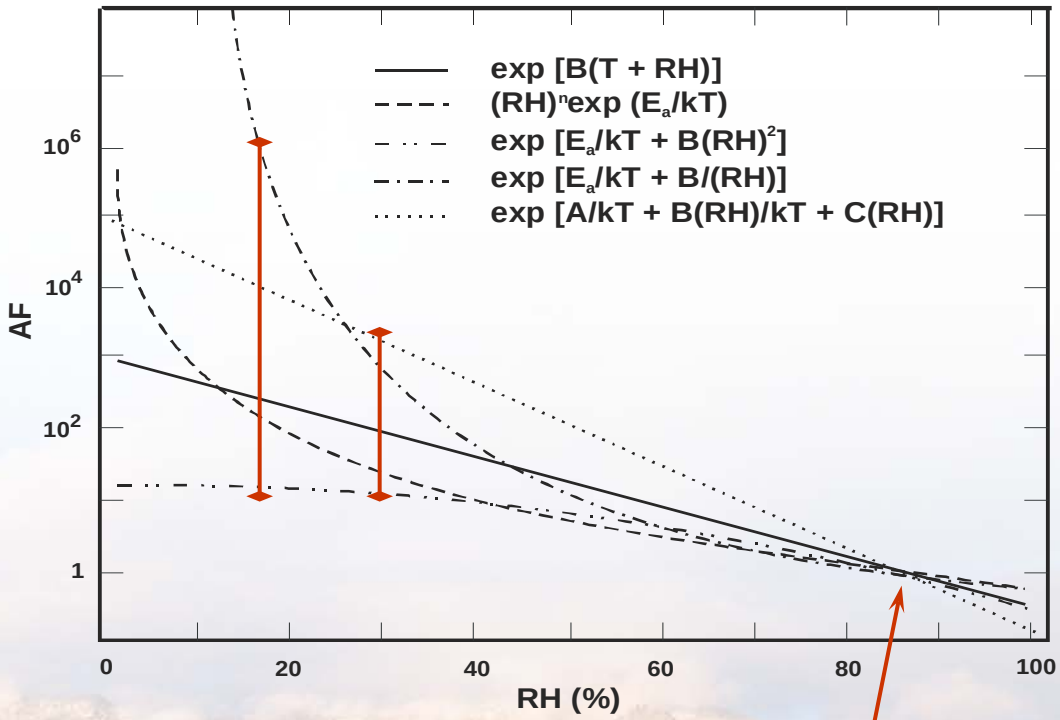
ALT must capture valid degradation / failure mechanisms

Five accepted environmental models.

All agree at 85% RH (ALT conditions).

Orders of magnitude difference at 30% RH (use conditions).

Atmospheric Corrosion of Micrelectronics



Calibration data collected here

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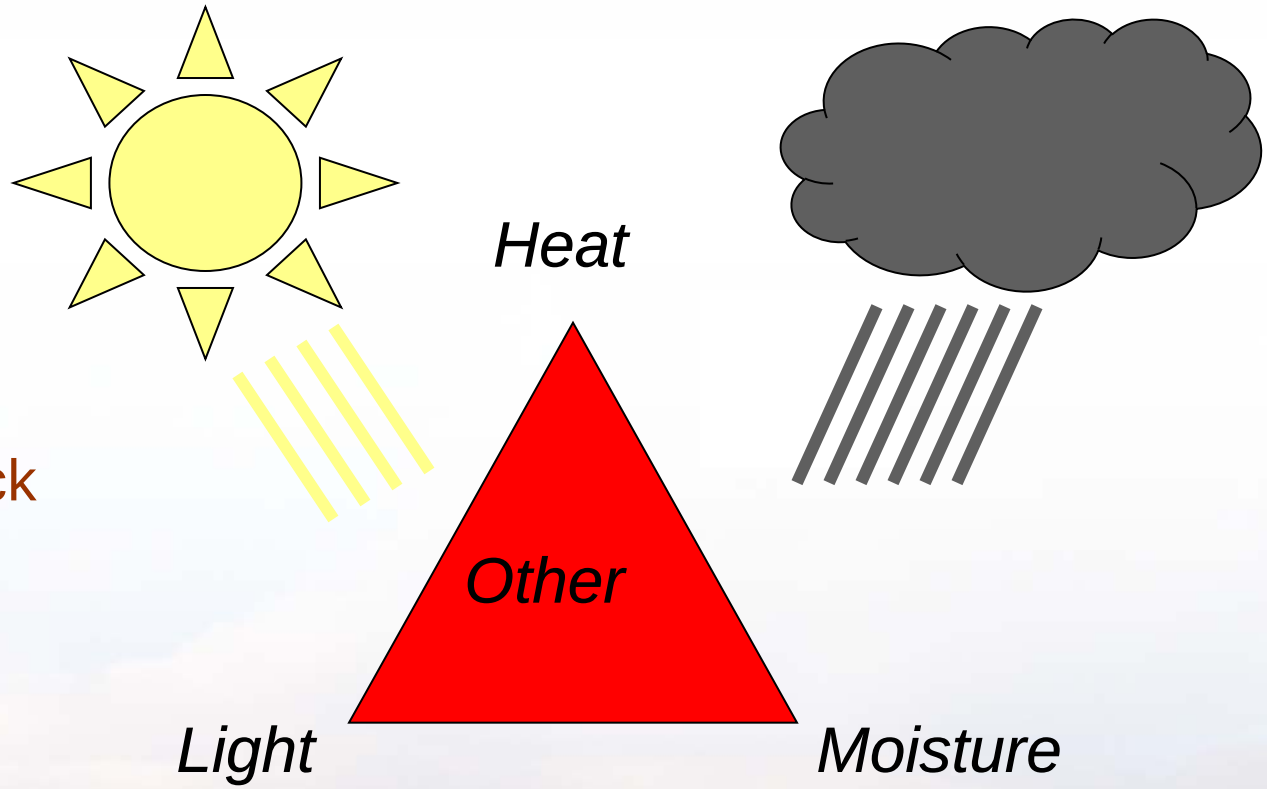
Issues with ALT

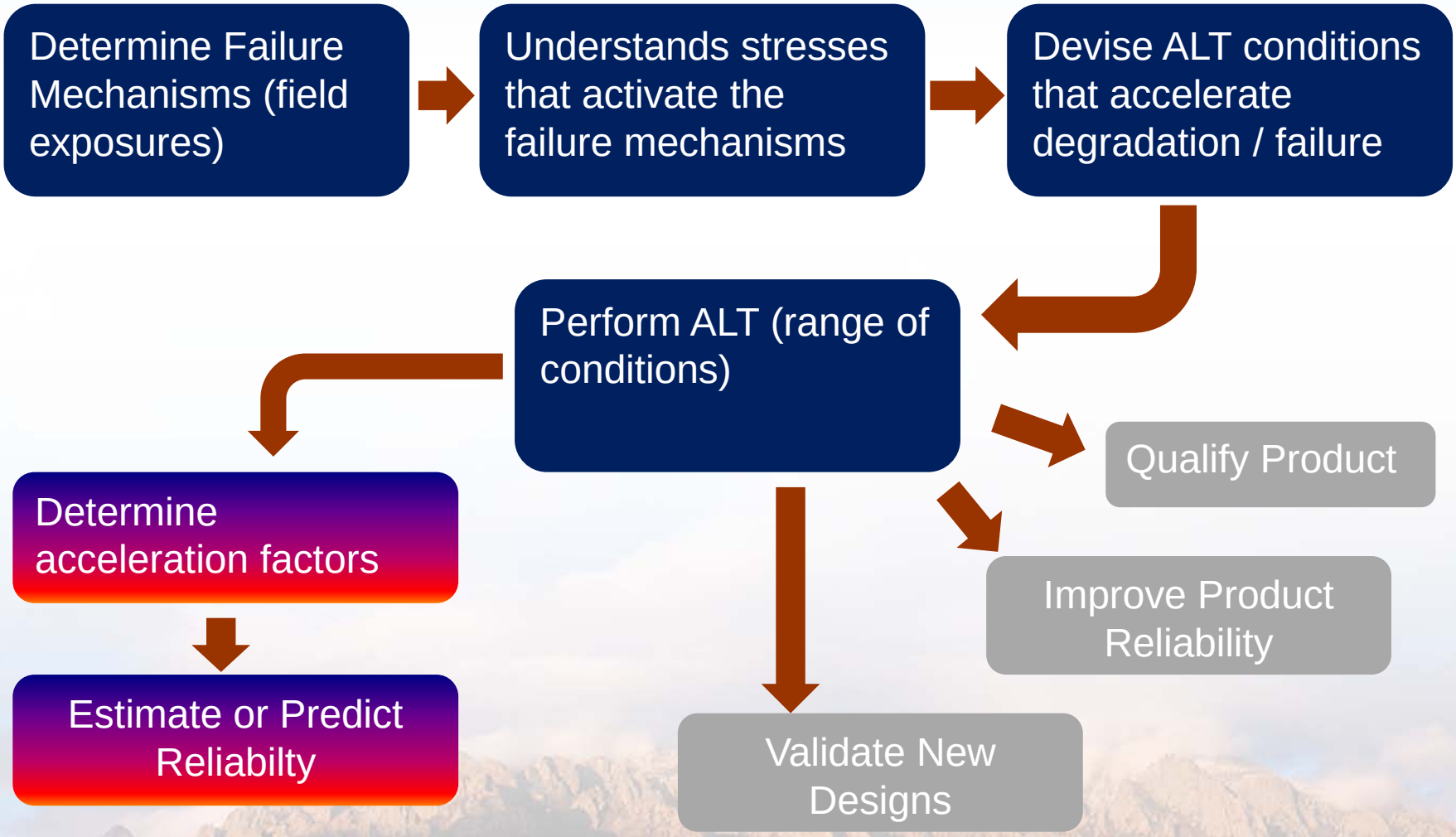
- Unknown failure mechanisms
- Unknown / variable use environment
- Changing mechanisms as function of environmental stress
- Difficult to control and characterize defects
- Long duration experiments
- Evolving / improving technology

What are the likely stresses that lead to Inverter Failure?

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

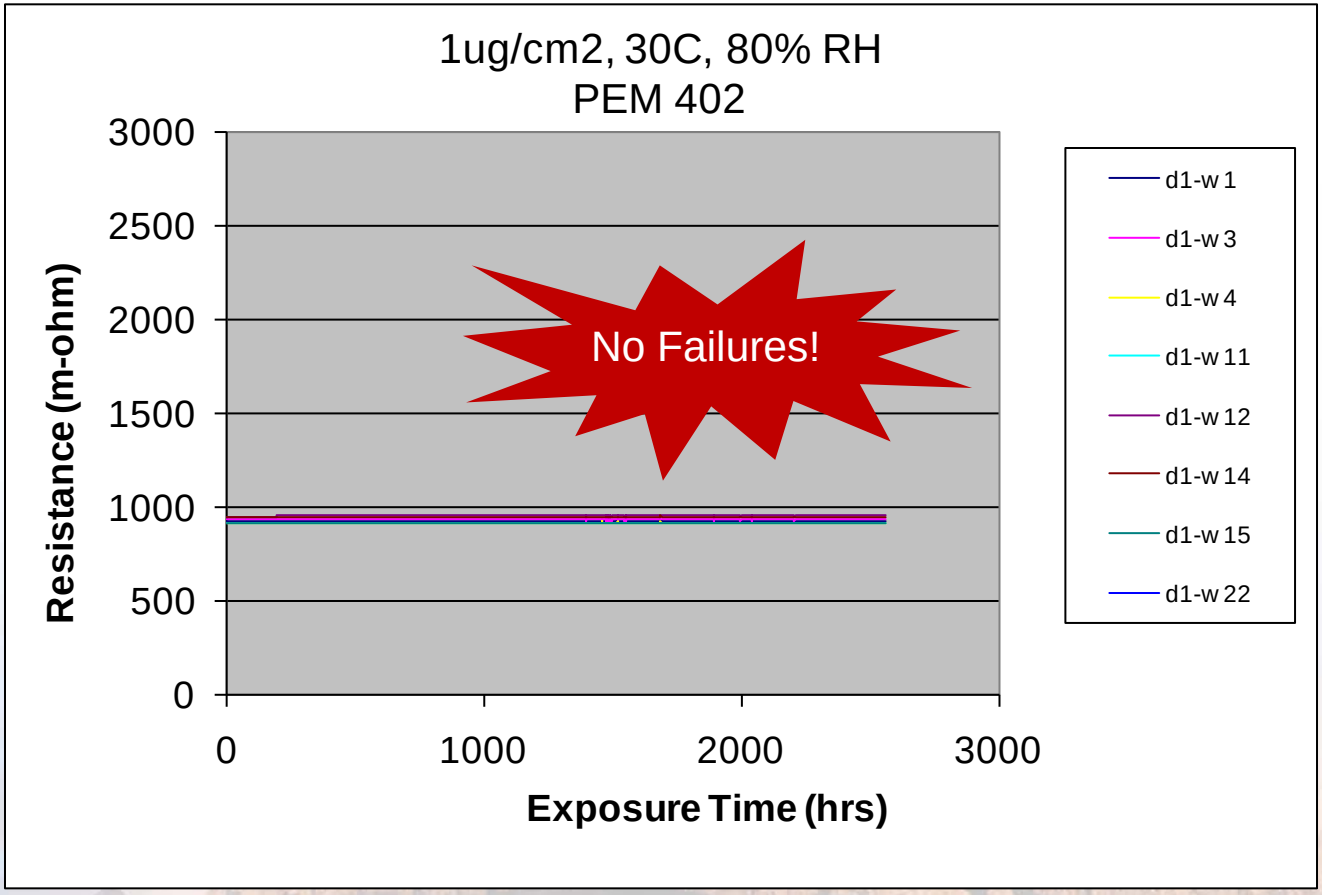


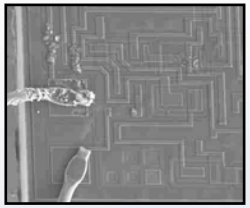
How do we apply ALT to predicting end-of-life (wear out)?



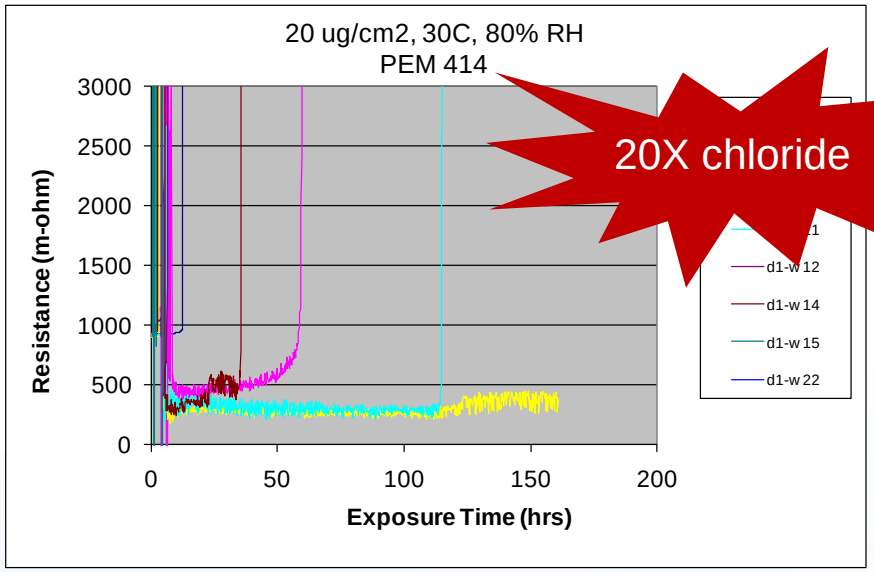
Example: Al bondpad corrosion: corrosion requires moisture and contamination & is accelerated by temperature.

Three environmental variables (T, RH, [Cl])





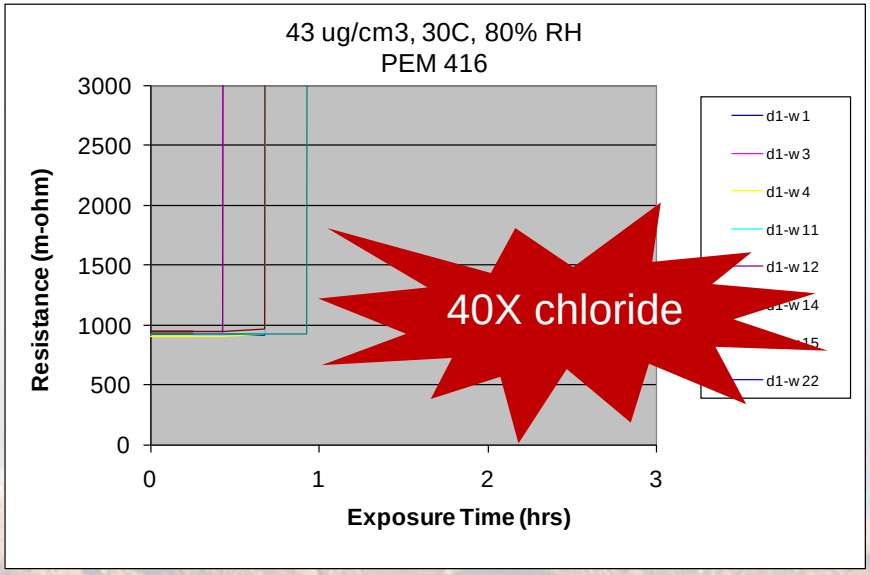
Increasing contaminant level causes failure.



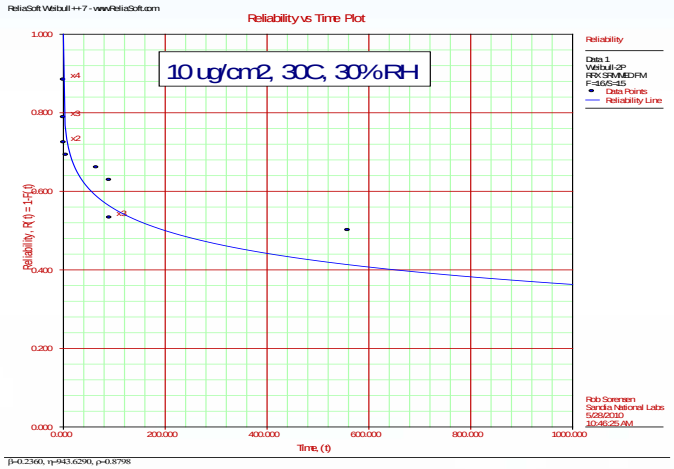
Distribution of failure times

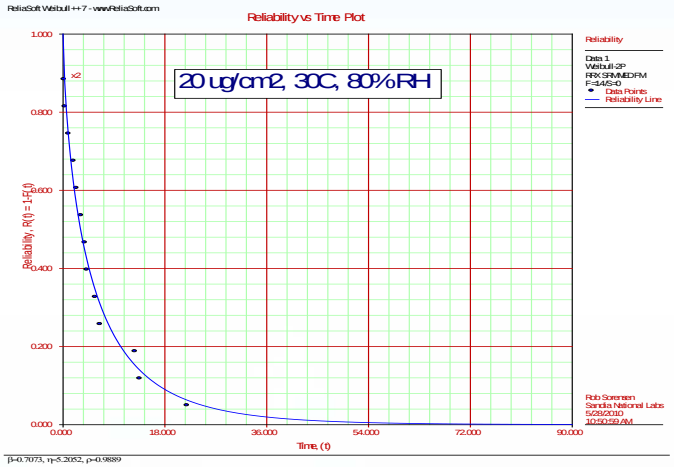
Not all failed

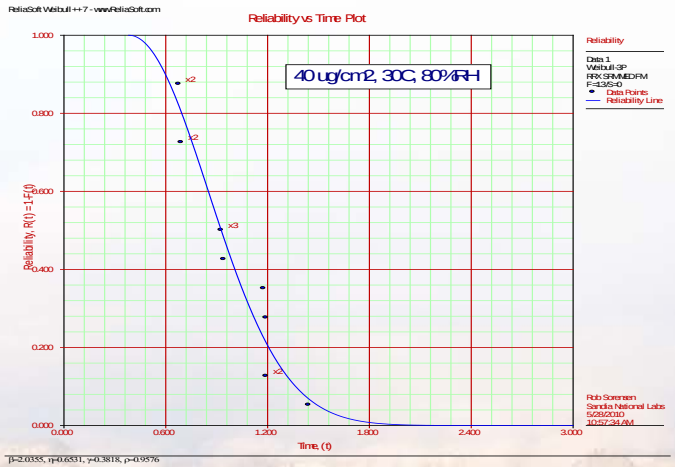
Clear effect of [Cl]



Statistical treatment (life-data analysis) provides a means of analyzing the bondpad data



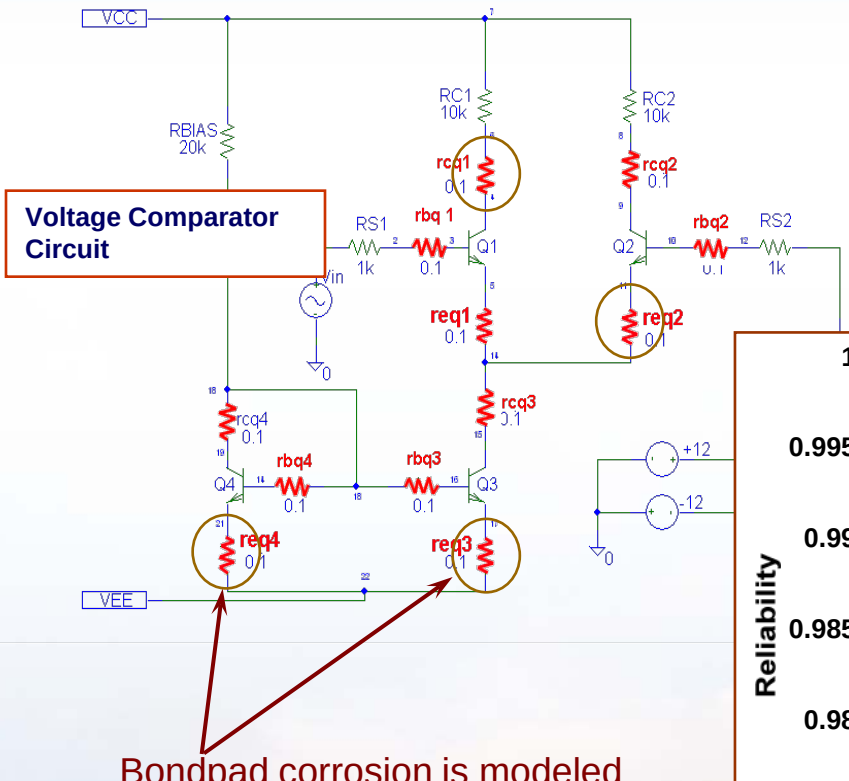




$$AF = \left(\frac{MTTF_{field}}{MTTF_{test}} \right)$$

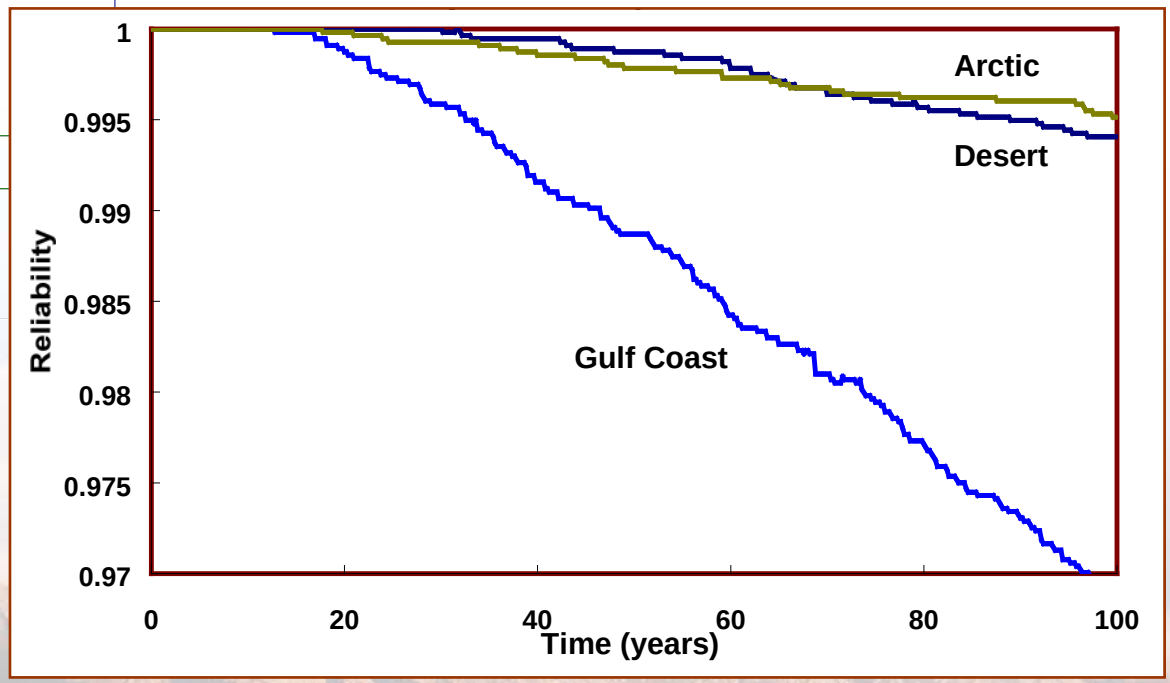
- Provides distributions
- Includes suspension results
- Basis for models {Pfail = f(T, RH, [Cl])}

The distributed wirebond property (probability of failure) is input into an electrical system model & other component outcomes (reliability, performance threshold) can be determined



Bondpad corrosion is modeled as an additional series resistor

Prediction of the effect of corrosion on LM185 reliability as f(storage location)



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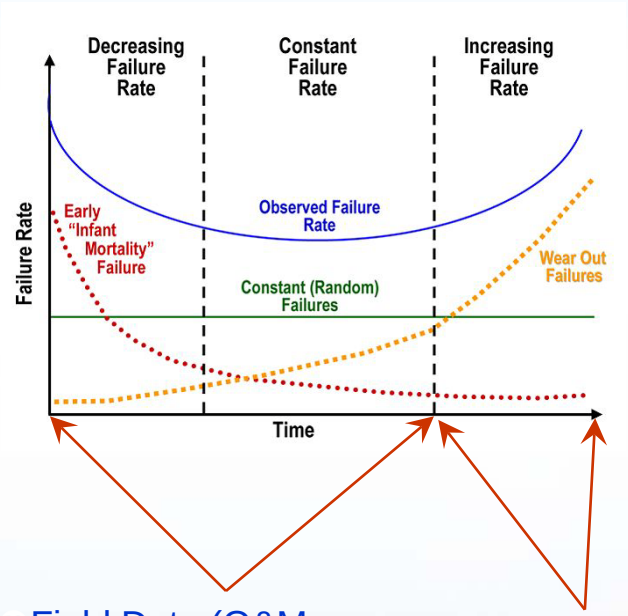

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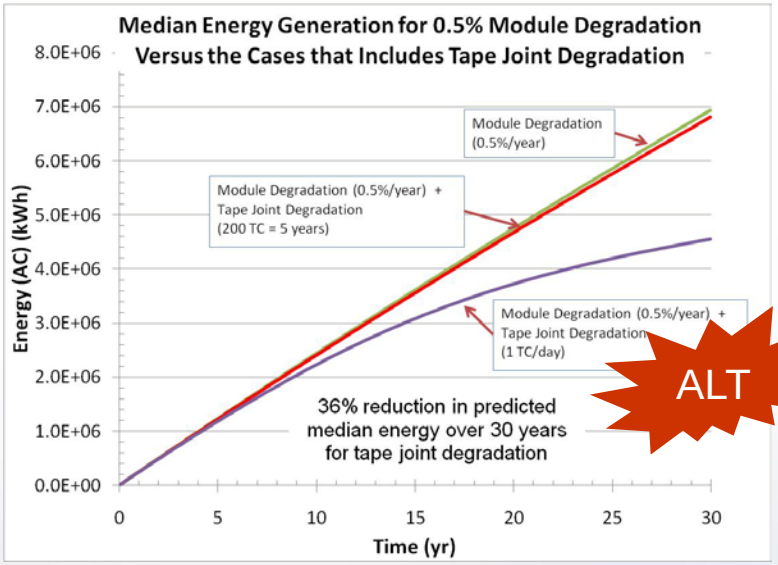

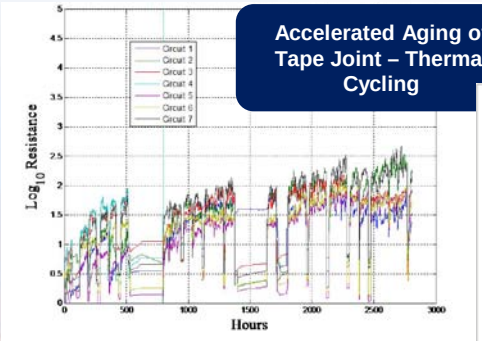

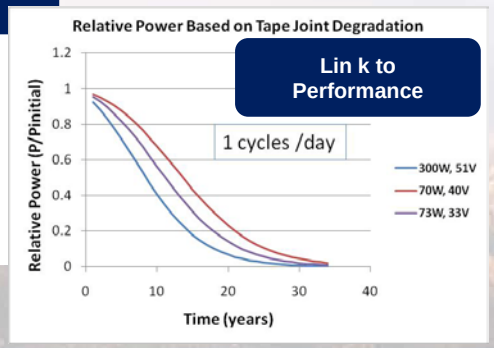

Acceleration Factors

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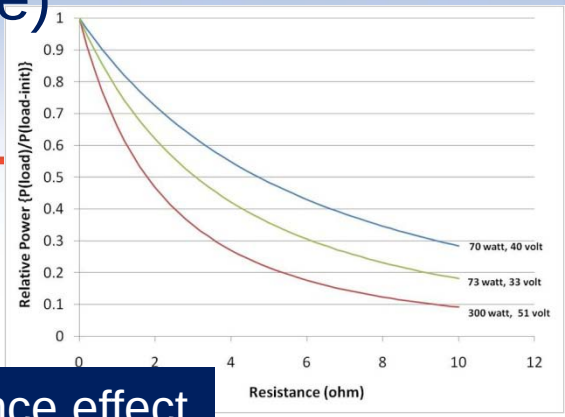
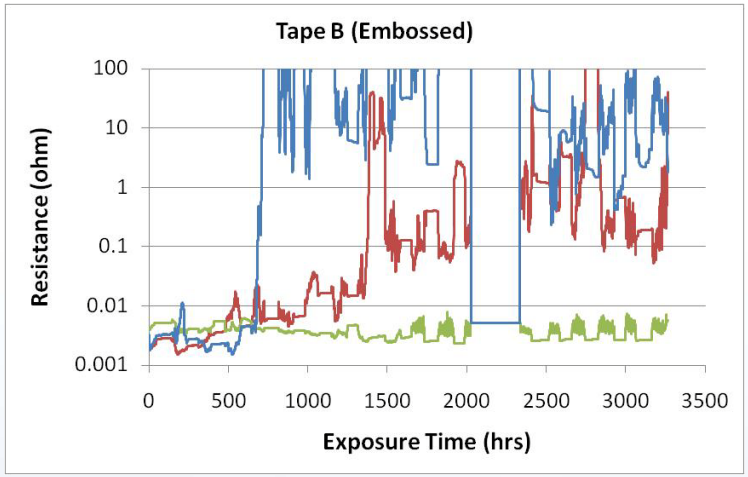
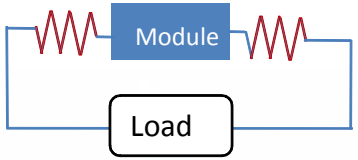
Example: Conductive metal foil tape (Module)



Generate ALT data

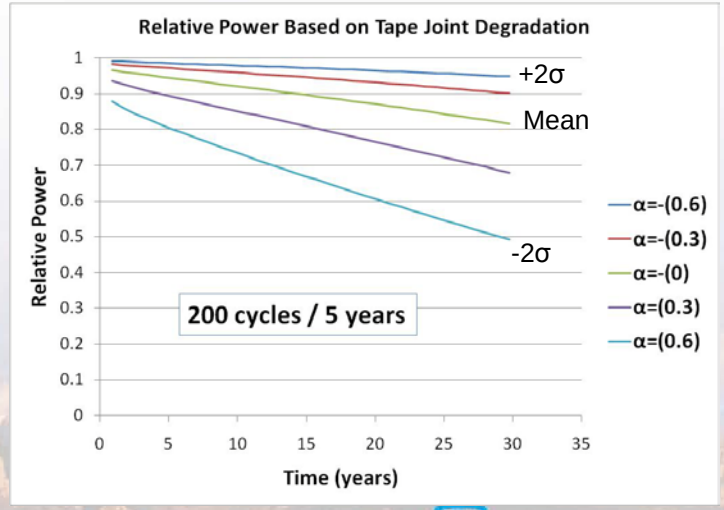


Determine performance effect



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

Apply acceleration factors to field



Develop "acceleration factors"

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

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